Carderock Division
Naval Surface Warfare Center
West Bethesda, MD 20817-5700

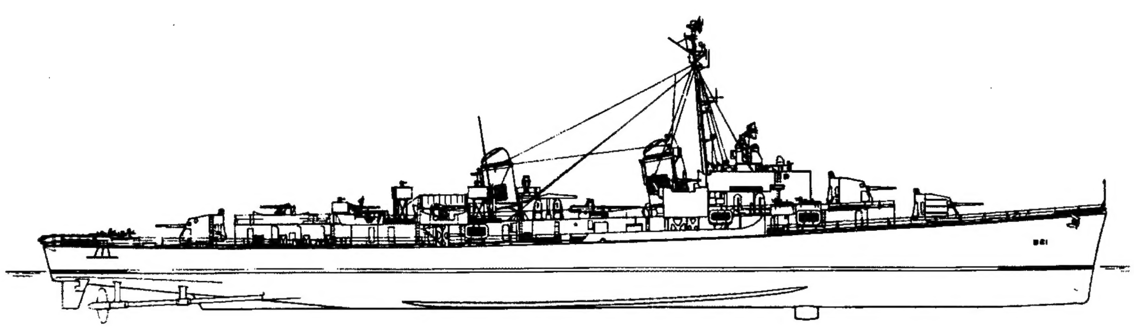
NSWCCD-TR-98/019 August 1998
Hydromechanics Directorate
Research and Development Report

An Investigation of the Scale Effect of Appendage Resistance of a Geometrically Similar Series of Models of the DD 710 Class

By
LTJG V. P. Klemm, USN
LTJG W. L. Buckingham, USN

19981231 008

Thesis Submitted to the Faculty of
Webb Institute of Naval Architecture
In Partial Fulfillment of the Requirements
For the Degree of Master of Science



Reprint permission and distribution clearance obtained by Robert F. Roddy, David Taylor Model Basin

Approved for public release; distribution is unlimited.

An Investigation of the Scale Effect of Appendage Resistance of a Geometrically Similar Series of Models of the DD 710 Class

NSWCCD-TR-98/019

AN INVESTIGATION OF THE SCALE EFFECT OF APPENDAGE RESISTANCE OF A GEOMETRICALLY SIMILAR SERIES OF MODELS OF THE DD 710 CLASS

A Thesis Submitted to the

Faculty of Webb Institute of Naval Architecture

in Partial Fulfillment of

the Requirements for the Degree of Master of Science

in

Naval Architecture

July 1954

by

LTJG V.P. Klemm, USN

and

LTJG W.L. Buckingham, USN

TABLE OF CONTENTS

PREFACE TO 2nd EDITION
(April 27,1990)

The work at the David W. Taylor Model Basin (now known as Carderock Division, NSWC) leading to the publishing of this Thesis was accomplished during a "Winter Work Period", January 1954 to March 1954, between academic semesters at WEBB INSTITUTE OF NAVAL ARCHITECTURE. The work at Webb Institute was accomplished during the period March 1954 to June 1954, immediately following.

After graduation from the Post Graduate School of the WEBB INSTITUTE OF NAVAL ARCHITECTURE on July 17, 1954, neither of the authors were assigned to any tour of duty which would have permitted any further study of this kind.

During the period January 1954 to March 1954, DTMB had a carriage operator assigned to the second shift to be available in the event that work on scheduled tests could not be finished in the first shift or had to be scheduled for two consecutive shifts. Because of the constraints placed on the salaried employees, second shifts were generally left open, so the authors were able to schedule as much time as they needed on the carriages, there being no cost to DTMB other than regularly scheduled employees, Thus, all questionable data could be rechecked. Occasionally, a day shift would be available. When that occurred, the authors would be on the carriage from 8 AM to midnight, stopping only when necessary to change carriage operators or grab a bite to eat. Needless to say, the next day was a day off.

The USS Timmerman DD 828, ne AG 152, (a DD 710 Class Hull) had been designated an engineering research and development test ship and had been instrumented (or so the authors had been told) to obtain data which could have been used to supplement the data in this report. No information is available as to whether such information ever became available. Timmerman was dismantled in 1957 and scrapped in 1958.

The authors are pleased to learn that this report has been useful to those who have been continuously involved in model testing. Our special thanks goes to Mr. Robert Roddy of DTMB, Carderock Division NSWC who undertook to have the classification removed so that the data could be made available to all who might have need of it.

ACKNOWLEDGMENTS

The authors wish to thank Cedric Ridgely-Nevitt, Professor of Naval Architecture, Webb Institute of Naval Architecture, for suggesting this topic for a thesis study, and for giving valuable aid and advice. We also wish to thank Captain Albert G. Mumma, Commanding Officer and Director, David W. Taylor Model Basin, for the use of the facilities of his command.

We also wish to thank the following named persons for their advice, counsel, and aid.

Mr. W.B. Hinterthan, David Taylor Model Basin
Mr. M.S. Harper, David Taylor Model Basin
Mr. G.R. Stuntz, David Taylor Model Basin
Mr. J.B. Hadler, David Taylor Model Basin
Capt. N.W. Gokey, USN (Ret'd) Webb Institute of Naval Architecture

SUMMARY

To the authors' knowledge, the only published work which deals with appendage scale effect as derived from a geosim series is entitled "Some Results of Scale Effect Experiments on a Twin Screw Hull Series", by J.F. Allan, DSc., a paper which was presented at the Ninety-Third Session of the Institution of Engineers and Shipbuilders in Scotland. This paper presented the results of a study of both shafting with struts and bossings for three models, 18.70 ft., 22.96 ft., and 33.67 ft. in length, over a range of speed-length ratios from 0.50 to 0.80. However, the hull form used was not typical of modern, high-speed naval vessels. This thesis investigates the appendage scale effect phenomenon for shafting and struts of a modern, high-speed Destroyer-type ship, using models of 4.494 ft., 12.00 ft., 20.759 ft., and 29.46 ft. in length, and covering a range of speed-length ratios from 0.55 to 2.05. The models were tested in three appendage conditions, (1) with all appendages, (AA), (2) with rudders removed (WR), and (3) with rudders, shafting, struts, and fairwaters removed (BH).

For this particular geosim series, there is a very definite scale effect, which effect varies according to the speed-length ratio, the scale effect being greatest at the lower speed-length ratios and diminishing at the higher speed-length ratios.

INTRODUCTION

The additional amount of resistance, which is added to the bare-hull resistance of a ship, upon the addition of appendages, such as shafts, struts, and rudders, is one of the many quantities which go into determining the horsepower required to drive the ship at a certain speed. It is, however, a quantity about which too little is known. Because appendage resistance does not follow any known law of similitude or comparison, it cannot be predicted by model tests. The usual procedure, in approximating the additional resistance to be added to the ship bare-hull resistance to account for the addition of appendages, is to add a part, usually one-half, of the additional resistance measured on model tests. If ship powers are to be more accurately predicted from model tests, the appendage resistance is one of the quantities which must be known to a higher degree of accuracy, say within 1%. And, if we are to more fully understand the actual flow conditions around models and ships, we must understand what takes place around these appendages. Many people may have been caused to shy away from studies of appendage resistance because this subject is so intimately tied in with other items of basic research, such as turbulence, frictional resistance, and boundary layers, which are presently being investigated and about which all too little is known. This study was undertaken with the idea of at least starting an investigation into the subject of appendage scale effect, which investigation it is hoped will encourage a further extension of this study and point the way for such a study.

The total resistance of an appendage, or a group of appendages, may be considered to consist of three parts: (1) frictional drag, (2) eddy-making and form resistance, and (3) interference resistance, or interaction between different appendages or between appendages and the hull. Much

work has been done in the testing of airfoil shapes both in water at speeds comparable to ship speeds, and in air at speeds comparable to airplane speeds. The results of these tests could be used to calculate parts (1) and (2) of the total appendage resistance, provided we knew the flow conditions around the airfoil section.

We should be able to determine the flow conditions in the vicinity of any given appendage by means of a pitot survey and then, using the test results mentioned above, we could calculate parts (1) and (2) mentioned above. If we could measure the resistance of each appendage separate from the resistance of the model, while the appendages are attached to the model, then by a simple process of subtraction, we could determine the magnitude of item (3). If we had this information for a geosim series, we could not only determine the appendage scale effect, but we could also establish the proportion of the scale effect due to each of the portions of the total appendage resistance.

In general, the measurements referred to above are complex and require special precision equipment. Since the amount of time and money necessary to design, construct and utilize this equipment is not available for this thesis, a simpler system of analysis must be employed.

Since all, or a portion, of each of the appendages lies within the boundary layer, the thickness of the boundary layer and the velocity distribution within that boundary layer will be of great importance in this investigation. Many theoretical and experimental investigations have been made to determine the thickness of the boundary layer and the velocity distribution within the boundary layer. The general consensus seems to be that the boundary layer thickness, δ, is proportional to the kinematic viscosity, ν, and the distance from the forward perpendicular, x, and inversely proportional to the velocity, V. The formulation which will be used in this thesis is the one contained in the U.S. Experimental Model Basin Report #193 and is:

$$\delta = 5.5\left(\frac{\nu x}{V}\right)^{1/2}$$

To place this formula in a form which will be more useful for a geosim series investigation, $\sqrt{L}$ times $V/\sqrt{L}$ is put in place of V, and a constant, c, times L is put in place of x. The formula then becomes:

$$\delta = 5.5\left(\frac{\nu c}{V/\sqrt{L}}\right)^{1/2}(L)^{1/4}$$

This means that the boundary layer thickness will not increase as rapidly as the appendage size increases, as the appendage size is proportional to L.

The velocity distribution inside the boundary layer is normally assumed in the form $V = V_0\,(\gamma\backslash\delta)^n$ where the values of n are between 1/5.5 and 1/9. The values normally used are n = 1/7 for the model case and n = 1/9 for the ship case.

It must be strongly emphasized that the validity of any of these formulations to flow in the way of the appendages is not known and the only method of actually determining either the boundary layer thickness or the velocity distribution inside the boundary layer is by direct measurement.

Since the more complete analysis outlined above could not be accomplished, the decision was made to treat this problem in its simplest terms and to adopt the "stripping method" of determining appendage resistance and concentrate on endeavoring to ascertain the variables which have the largest influence on the appendage scale effect.

PROCEDURE

The four models tested were geosims of the DD 710. Models numbered 3878-1 (L=20.759 ft.), 4007 (L=12.00 ft.), and 4514 (L=29.46 ft.) were built by David W. Taylor Model Basin, and model number 4507 (L=4.494 ft.) was built by the Newport News Shipbuilding and Drydock Company. Model 4507 was built from plans based on twenty equally spaced stations, and the models built by DTMB were built from plans of the DD 692 class, with an addition of fourteen feet added between stations 10 and 11. All models were rough cut with station cutters, faired by hand, sanded and sealed. The painting system consisted of one coat of flat white primer, one undercoat of French Grey enamel and one coat of French Grey enamel. The models were rubbed smooth between coats. The model characteristics are listed on PLATE I.

The DD 710 has twin screw propulsion and twin rudders. The appendages for these tests consisted of sound dome, bilge keels, stern tubes, intermediate and main two-arm struts, shafts, propeller hubs, and rudders. The appendages for the separate models are listed on PLATE I. All of the appendages were made so that they could be easily removed from the model. The bilge keels and sound domes remained attached to the model during all of the tests. The three appendage conditions reported in this paper are: (1) all appendages in place on the model (AA); (2) all appendages in place, but with rudders removed (WR); and, (3) bare hull with the sound dome and bilge keels in place (BH). Two additional conditions were originally planned to be used in conjunction with pitot tube survey data, but this data was not obtained. These conditions were (4) bare hull with sound dome, bilge keels, and rudders in place, and (5) all appendages, with rudders, main struts, after-section of shafting and propeller hubs removed.

In all cases, the removal of appendages left holes in the hull of the model. These holes were filled with Plasteline modeling clay, which was faired into the lines of the hull and made as smooth as possible. This process proved very satisfactory.

Models 3878-1, 4007 and 4514 were tested on Carriage #1 at the David Taylor Model Basin by the authors during the period January 4, 1954 to March 25, 1954. Before any model was placed into the water, it was wiped clean of dust or grease and checked for any irregularity. The model would then be weighed, placed in the water and ballasted. The ballast weights were then adjusted to give the desired trim. If, in this condition, the actual draft readings were within one-hundredth

of a foot of the values calculated from the lines of the ship, the actual draft readings were accepted. In all the models in this series, this accuracy was met or bettered.

Models 3878-1 and 4514 were towed from a point about one-third the length from the forward perpendicular, and at the waterline. Model 4007 was towed at about station 8 and a point about two inches above the waterline. It was determined by tests that this change in location had no appreciable effect on the measured resistance. This change in towing point on model 4007 was made to accommodate a strain gage type dynamometer which was unsuccessfully used in attempting to increase the accuracy of measuring the small resistance values. All models were attached, at a point on the stern, to a counterbalance arm, which had as its purpose the holding of the model on a steady course, both in the ahead and astern directions. In addition, model 4007 was guided by two horizontal parallel roller bars at the bow which enclosed a rigid vertical bar that was attached to the towing girder.

The same procedure of preparation was used on model 4507 at Webb Institute of Naval Architecture, except that the model was washed before each test with Murphy's Oil Soap and wiped with paper toweling. On this small model, it was necessary to fasten the weights to the model in order to prevent shifting of the weights during the tests. An acceleration strut, which was rigidly attached to the towing carriage, passed through a square hole in a plate fastened to the deck of the model and took acceleration and reversing loads off of the dynamometer. Model 4007 was towed from the bow by a horizontal arm which was located three inches above the waterline. This arm had freedom of motion in a vertical plane to permit the model to trim freely.

In the actual testing of the models at the David Taylor Model Basin, the normal procedure for EHP tests was followed. A time interval (measured from start to start) of fifteen minutes for model 4514, twelve minutes for model 3878-1 and ten minutes for model 4007, was used. No damping was used, except on model 4514 at high speeds, at which condition it became necessary to use damping in order to keep the oscillations within the limits of the dynamometer.

The standard procedure of the Webb Institute Testing Tank was used on model 4507. Here also damping was used only when absolutely necessary to prevent the oscillations from becoming too great. The time interval from start to start of the runs varied from two and one-half to three minutes for this model. This range was determined to be sufficient after testing with intervals as large as five minutes.

The lightest possible springs were used in all the tests at DTMB, in order to permit the largest practicable oscillations. This naturally damped sinusoidal motion was recorded by a stylus pen, and the accurate values of resistance were determined by evaluating these oscillations. It was necessary to use two different springs on model 4514, a lighter spring at the lower values of speed-length ratio (0.55 to 1.20) and a heavier spring at the higher speed length ratios (1.20 to 2.05). At these higher speed-length ratios, it was necessary to make two runs down the basin for each speed, in order to obtain sufficient oscillations for a proper evaluation.

During the testing of model 4507, the tank temperature varied from about 70° F to about 78° F. However, the temperature did not vary over one-half of one degree during any one test. Some of the tests on model 4507 were not included because the temperature was determined to have varied too much from the mean value of 73° F. Arbitrary limits were set upon the scale readings which would be acceptable for inclusion in these tests. After all of the points of the various tests were calculated and plotted, it was decided that the scatter of points was too great and these arbitrary limits were further decreased with the consequent result that many additional runs were not used, or included in the data presented here.

The procedure followed in calculating and plotting the results of these test is as follows: the values of speed, water temperature, and total resistance for each test were used to calculate values of Reynolds number and total resistance coefficient, C_t. Using the values of Reynolds number, values of Schoenherr Friction Coefficient, C_f, were obtained, which values were subtracted from the values of C_t to give values of residuary resistance coefficient, C_r. These values of C_r were plotted versus speed-length ratio, the values for all tests of one model being plotted on one sheet. The curves of C_r were then faired, and values were picked off these faired curves for speed-length ratios of 0.55 to 2.05 for every .05 increment. These values were then used in calculation sheets, listed as Plates XIX-XXII. Values of C_f ship correspond to a temperature of 59° F, sea water.

RESULTS

The curves of C_r versus speed-length ratio are presented as Plates XVI to XVIII. They are presented here with one appendage condition for all four models on the same sheet, although this is not the way that the curves were originally faired. This presentation was chosen to aid in the discussion of the results.

The true results of this thesis-that is, the resistance of the appendages and the scale effect of that resistance, when going from one model size to another size-are presented in several ways in an attempt to arrive at a method which most clearly shows the scale effect and permits of easy extrapolation to the full scale ship size. These presentations are as follows:

Plate XXIII - Appendage Resistance of Rudders and of Shafts and Struts-expressed as a percent of bare-hull resistance expanded to ship size and plotted versus speed-length ratio.

Plate XXIV - Total Appendage Resistance expressed as a percent of bare-hull resistance expanded to ship size and plotted versus speed-length ratio.

Plate XXV - Appendage Resistance of Rudders and of Shafts and Struts, plotted versus the logarithm to the base ten of Reynold's Number.

Plate XXVI - Appendage Resistance of Shafts and Struts plotted versus the logarithm to the base ten of Reynold's Number, for specific speed-length ratios.

Plate XXVIII- Appendage Resistance of Shafts and Struts expressed as a percent of bare-hull resistance expanded to ship size and plotted versus the boundary layer thickness.

Plate XXIX - Appendage Resistance of Rudders expressed as a percent of bare hull resistance expanded to ship size and plotted versus the boundary layer thickness.

DISCUSSION OF RESULTS

Plates XVI to XVIII show very clearly the humps in the C_r curves which occur at speed-length ratios 0.6, 0.8, 1.0 and 1.6. Humps also occur on Plates XXV, XXVI, XXVIII and XXIX at these same speed-length ratios.

The curves of C_r show that there was no appreciable wall or bottom effect on model 4514, which agrees with calculations made using the "Landweber Method" found in David Taylor Model Basin Report #460.

Both model 4007 and model 4507 were tested with turbulence stimulating devices in order to insure that turbulent flow existed at the lower speed- length ratios. Model 4007 was tested with the following devices:

1/8" diameter rod, vertically immersed 6", located 7" ahead of the model,
1/2" wide sand strip, 20-30 sand at 0.05 L from the bow,
0.035" diameter trip wire at 0.05 L from the bow,
0.140" diameter, 0.035" high studs placed 1/2" center to center at 0.05 L from the bow.

These tests showed that there was no appreciable difference from tests with no turbulence stimulating device. Model 4507 was tested with a 1/8" diameter turbulence rod sloping forward at 30° from the vertical, immersed 3 1/2" and located 4" ahead of the model. Here, also, there was no appreciable difference in resistance from tests without the turbulence rod. Because of the results of the turbulence tests on model 4007, no other devices were tried on model 4507.

An incidental result of the series is evidenced on plate XVIII. This plate shows the very close agreement between the C_r curves of the bare hull condition for all four models. In fact, the only difference between the four curves is that the smaller models (4507 and 4007) show lower values

of C_r up to speed-length ratio 1.2, and higher values of C_r above speed-length ratio 1.4. This difference could quite easily be explained by saying that the smaller the model, the more accentuated are the humps. However, the important fact is that the maximum difference between any two curves, at speed-length ratio 1.65, is 0.0039 - 0.00373 or 0.00025 which is less than the usual roughness correction of 0.0004 and only one-third of the roughness correction for plastic bottom paint, 0.00075.

Plates XXIII and XXIV, the curves of percent of appendage resistance versus speed-length ratio, show a very definite appendage scale effect, which seems to be concentrated mostly in the shafts and struts. However, these curves do not show the method of variation of the scale effect, and do not give a method of extrapolating to ship size. Therefore, the data are presented in two additional forms.

Plate XXV indicates that the curve of appendage resistance due to shafts and struts is similar to a damped sinusoidal oscillation. This agrees with the statement made earlier, that is, the smaller the model, the more pronounced are the humps in the C_r curves. For, it is these humps, and the manner in which they were faired, which cause the values of ΔC_t to depart from a smooth curve. The curve which is drawn on this plot asymptotically approaches a value of ΔC_t of about 0.00015 at a value of $Log_{10} N_R$ of 9.5 which is the approximate ship range. A comparison of this value and the value obtained for the ship range from Plate XXVIII will be made later.

The plot of appendage resistance due to rudders shows a damped oscillation similar to the oscillation in the plot of appendage resistance due to shafts and struts. However, the individual models do not lie on the same curve, but lie, instead, on a series of practically parallel curves. Therefore, two bounding curves are shown. The lower bounding curve is for low speed-length ratios and the upper bounding curve is for high speed-length ratios. The curve for the low speed-length ratios is very nearly horizontal in the range covered by models 4514, 3878-1, and 4007 with a value of ΔC_t of 0.00004. The curve for the higher speed-length ratios is also very nearly horizontal in the range covered by models 4514, 3878-1 and 4007 with a value of ΔC_t of 0.000165. These values will also be compared later with values obtained from other plots.

Plate XXVI shows how very nearly parallel are the curves of ΔC_t versus $Log_{10} N_R$ for speed-length ratios above 1.40. Once again in the region of the humps in the C_r curves, this plot is very confusing. However, below speed- length ratios of 0.80 the curves are once again very nearly parallel. Also, in the region below a speed-length ratio of 0.80, the comparison between the results of this series and the series of Dr. Allan is shown.

Plate XXVIII shows the same consistency in the speed-length ratios above 1.60 as was evidenced in Plates XXIII and XXV. Four curves are drawn on Plate XXVIII to show the gradual lessening of slope of the curves of ΔC_t versus δ for specific speed-length ratios as the speed-length ratio increases. But, once again in the region of the humps in the C_r curves, it is impossible to follow a consistent trend. And, once again in the range above the speed-length ratio 1.60, the curves of ΔC_t versus δ for specific speed-length ratios are nearly coincident. For this plot a single curve

has been drawn to represent the curves for speed-length ratios above 1.60. According to formulation used here for boundary layer thickness, the boundary layer thickness for the ship at a speed-length ratio of 2.00 would be about 0.60". At this point, the curve would give a value for percent of bare hull resistance which must be aided to the bare hull resistance to account for shafts and struts as 3%. From Plate XXV, the percent would be 0.00015÷0.005 (approximate value of C_t ship at a speed-length ratio of 2.00) or 3%. From Plate XXIII, the value for percent of bare hull resistance which must be added to the bare hull resistance to account for shafts and struts is: model 4514, 4.2%, model 3878-1, 5.0%, model 4007, 5.4%, model 4507, 8.2%.

Plate XXIX, once again, shows the consistency of the values of ΔC_t for speed-length ratios above 1.60, but in this case, models 4514, 3878-1 and 4007 all seem to follow one horizontal line, i.e. 3.5%, while model 4507 follows another horizontal line, i.e. 6.0%. However, in this plot one single curve has been drawn representing a mean of all of the points, except the points for speed-length ratios less than 1.10 for model 4507. This curve gives a value of about 1% for the ship range, while from Plate XXV, the curve for low speed- length ratios gives 0.00004÷ 0.0025=1.6%. (0.0025 is the value of C_t for the .speed-length ratio of 0.80) The curve for the high speed-length ratios gives 0.000165÷0.005=3.3%. (0.005 is the value of C_t for the speed-length ratio of 2.00). A horizontal line through the high speed-length ratios of the models 4514, 3878-1 and 4007 gives 3.5%. From Plate XXIII, the values of percent of bare hull resistance which must be added to account for rudders is: model 4514, 3.8%, model 3878-1, 3.4%, model 4007, 3.7%, model 4507, 3.7%.

CONCLUSIONS

As was pointed out in the discussion of the results of Plate XVIII, the bare hull curves of C_r for the four models in this geosim series are practically identical, the maximum variation being less than the roughness correction usually applied in the expansion of results to full size. Therefore, there is no model scale effect in this series.

There is a definite appendage scale effect for the shafts and struts. Appendage resistance determined by model tests must be multiplied by a correction for another size model or the full scale ship. This correction factor varies inversely as the speed- length ratio and directly as the scale ratio. However, for the range of models from 12.00 to 30.00 feet in length and for the speed-length ratios above 1.50, a correction factor of roughly 0.75 may be used to predict for the ship.

For the range of models 12.00 to 30.00 feet in length, there is no scale effect of appendage resistance due to rudders.

In the predicting of either EHP or appendage resistance for ships of this type, it is not advisable to use model results from a model as small as 4½ feet in length.

RECOMMENDATIONS

There is a large gap in the region between the 12.00 and the 4.494 feet in length models. Therefore, in order to explore this region, a model of and intermediate length, say 8.00 feet in length, should be tested.

This thesis has been unable to determine a method of plotting the additional resistance or the percent additional resistance due to rudders which would explain what happens around this appendage. Consequently, additional methods of plotting could be tried in attempting to explain these results.

The curves which are shown on Plates XXV, XXVI, XXVIII, and XXIX should have equations written for them, in an attempt to explain more fully the effect of basic variables on appendage resistance and scale effect.

This work definitely points to the necessity of determining the actual values of boundary layer thickness and the velocity distribution within this layer in the regions of the major appendages, so that actual values can be used in the plots of appendage resistance versus boundary layer thickness. Also, calculations could then be made to determine what portion of the appendage resistance is frictional, what portion is due to wave making and separation and what portion is due to interference or interaction.

Since this hull form is limited in its applications and usage, additional series of this type should be done on other hull forms to determine if the same type of variance of appendage resistance is true on those forms or if there is an entirely different appendage scale effect for each individual hull form and set of appendages.

BIBLIOGRAPHY

(1) Allan, J.F. "Some Results of Scale Effect Experiments on a Twin Screw Hull Series", Transactions of the Institution of Engineers and Shipbuilders in Scotland, Vol. 93, 1949-1950, pp. 353-382.

(2) Allan, J.F. "Wake Studies of Plane Surfaces", Transactions of the North East Coast of Engineers and Shipbuilders (London), Vol. 69, 1952-1953, pp. 245-267.

(3) Baker, G.S. Ship Design, Resistance and Screw Propulsion. Second Edition. Liverpool: Charles Birchall and Sons Ltd., 1948.

(4) Dyson, Charles W., RAdm, USN Screw Propellers and Estimation of Power for Propulsion of Ships Also Airship Propellers. Third Edition. New York: Simmons-Boardman, 1924.Vols. I and II.

(5) Hay, A. Donald Flow About Semi-Submerged Cylinders of Finite Length.

(6) Hoerner, Sighard F. Aerodynamic Drag. Sighard F. Hoerner, 1951.

(7) National Advisory Committee for Aeronautics, Technical Memorandum numbers 1216, 1217 and 1218.

(8) David Taylor Model Basin, Report number 460. "Fractional Resistance"

(9) U.S. Experimental Model Basin, Report number 193, "Tests of a Model in Restricted Channels"

APPENDIX

PLATE I - TABLE OF CHARACTERISTICS

	Trial	**4514**	**3878-1**	**4007**	**4507**
LWL (feet)	383.0	29.46	20.759	12.00	4.494
LOA (feet)	390.5	30.04	21.160	12.235	4.582
Displacement	3250.Tons	3241.33#	1133.87#	219.06#	11.50#
Max. Beam (feet)	40.39	3.145	2.216	1.281	0.480
Mean Draft (feet)	13.713*	1.055	0.743	0.430	0.161
Draft For'd	13.213*	1.016	0.716	0.414	0.155
Draft Aft	14.213*	1.093	0.770	0.445	0.167
Surface, BH(ft)^2	17264.	102.153	50.716	16.949	2.377
Surface, Rud	292.75	1.732	0.860	0.287	0.040
Surface, Bil. Kl.	740.38	4.381	2.175	0.727	0.102
Surface, Sd. Dme.	72.50	0.429	0.213	0.071	0.010
Surface, Total	**18370.**	**108.698**	**53.966**	**18.035**	**2.529**
Scale Ratio	1.00	13.00	18.45	31.915	85.225
Bilge Keel	P.M.@	P.M.@	P.M.@	P.M.@	P.M.@
Sound Dome	P.M.@	Wooden	Wooden	Wooden	Wooden
Rudders	P.M.@	Wooden	P.M.@	Wooden	Wooden
Struts		White Metal	White Metal	White Metal	Brass
Shafts		Wooden	Brass	Wooden	Brass
Fairwater		Wooden	Wooden	Wooden	Wooden
Accuracies					
Speed (Knots)		0.005	0.005	0.005	0.005
Resistance (Lbs.)		0.05&0.10	0.02	0.01	0.001

*These values are in sea water of specific gravity of 1.0223
@Painted Metal

PLATE II - Model 4514 Test 1 AA And 6 AA Results

DD 710 D.T.M.B MODEL 4514 L.B.P. 29.46 ft.

TEST 1 AA

TEMP. F.W. 63oF ν 1.1605×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.3270 \times 10^{7}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^{7}$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.553	1.286	3.810	2.818	0.992
0.599	1.393	3.878	2.782	1.096
0.645	1.500	3.886	2.749	1.137
0.690	1.606	3.965	2.720	1.245
0.737	1.715	4.016	2.692	1.324
0.784	1.824	4.046	2.666	1.380
0.833	1.938	4.106	2.640	1.466
0.875	2.036	4.132	2.621	1.511
0.878	2.044	4.117	2.619	1.498
0.925	2.152	4.214	2.599	1.615
0.967	2.251	4.397	2.580	1.817
1.013	2.358	4.512	2.562	1.950
1.059	2.465	4.582	2.544	2.038
1.105	2.572	4.596	2.528	2.068
1.150	2.675	4.634	2.513	2.121
1.199	2.791	5.690	2.497	2.193
1.244	2.894	4.903	2.483	2.420
1.290	3.001	5.150	2.470	2.680
1.332	3.100	5.477	2.457	3.020
1.335	3.106	5.435	2.456	2.979
1.382	3.216	5.806	2.443	3.363
1.384	3.220	5.743	2.443	3.300
1.429	3.325	6.006	2.432	3.574
1.474	3.430	6.200	2.420	3.780
1.474	3.430	6.159	2.420	3.739
1.519	3.535	6.366	2.410	3.956
1.570	3.653	6.420	2.398	4.022
1.658	3.859	6.547	2.379	4.168
1.750	4.073	6.447	2.359	4.088
1.842	4.287	6.342	2.341	4.001
1.842	4.287	6.318	2.341	3.977
1.938	4.510	6.136	2.324	3.812

TEST 6 AA
Supp. 1 AA

TEMP. F.W. 63oF ν 1.1605×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.3270 \times 10^{7}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^{7}$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.553	1.288	3.819	2.817	1.002
0.600	1.396	3.878	2.781	1.097
0.645	1.500	3.926	2.749	1.177
0.697	1.608	3.989	2.719	1.270
0.736	1.713	4.025	2.692	1.333
0.785	1.826	4.044	2.666	1.378
0.830	1.932	4.114	2.642	1.472
0.877	2.041	4.157	2.620	1.537
0.921	2.144	4.247	2.600	1.647
0.969	2.255	4.379	2.579	1.800
0.108	2.579	4.591	2.527	2.064
1.199	2.791	4.725	2.497	2.228

PLATE III - Model 4514 Test 2 WR, 3 WR, and 5 WR Results

DD 710 D.T.M.B MODEL 4514 L.B.P. 29.46 ft.

TEST 2&5 WR

TEMP. F.W. 63ºF ν $1.1605\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.3270\text{x}10^{7}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^7$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.554	1.288	3.802	2.817	0.985
0.601	1.398	3.867	2.781	1.086
0.645	1.501	3.921	2.749	1.172
0.693	1.612	3.947	2.718	1.229
0.737	1.715	3.954	2.692	1.262
0.787	1.831	3.980	2.665	1.315
0.832	1.936	4.065	2.641	1.424
0.879	2.045	4.119	2.619	1.500
0.923	2.148	4.205	2.599	1.606
0.972	2.262	4.279	2.585	1.694
1.016	2.364	4.470	2.561	1.909
1.060	2.467	4.535	2.544	1.991
1.107	2.577	4.477	2.527	1.950
1.153	2.684	4.480	2.519	1.961
1.199	2.789	4.556	2.497	2.059
1.245	2.896	4.782	2.483	2.299
0.555	1.290	3.789	2.816	0.973
0.599	1.393	3.860	2.782	1.078
0.645	1.501	3.879	2.749	1.130
0.690	1.606	3.945	2.720	1.225
0.737	1.715	3.943	2.692	1.251
0.783	1.822	3.980	2.667	1.313
0.830	1.932	4.091	2.642	1.449
0.876	2.039	4.114	2.620	1.494
0.922	2.146	4.172	2.599	1.573
1.013	2.351	4.438	2.562	1.876
1.058	2.461	4.505	2.545	1.960
1.060	2.467	4.483	2.544	1.939

TEST 3 WR

TEMP. F.W. 63ºF ν $1.1687\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.3270\text{x}10^{7}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^7$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
1.292	2.986	5.052	2.471	2.581
1.336	3.086	5.316	2.459	2.857
1.384	3.197	5.626	2.446	3.180
1.430	3.304	5.819	2.434	3.385
1.474	3.406	6.052	2.422	3.630
1.521	3.514	6.180	2.412	3.768
1.564	3.614	6.260	2.402	3.858
1.657	3.829	6.342	2.381	3.961
1.750	4.044	6.285	2.362	3.923
1.845	4.264	6.104	2.342	3.762
1.942	4.487	5.938	2.325	3.613
2.030	4.692	5.794	2.310	3.484

PLATE IV - Model 4514 Test 4 BH Results

DD 710 D.T.M.B MODEL 4514 L.B.P. 29.46 ft.

TEST 4 BH TEST ______

TEMP. F.W. 62.5°F ν 1.1687×10^{-5} TEMP. F.W. _____ ν ________

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.3107 \times 10^{7} \qquad \frac{1.6889(L)^{3/2}}{\nu} = \_\_\_\_\_\_$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^7$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.553	1.278	3.564	2.820	0.744
0.599	1.384	3.620	2.785	0.835
0.645	1.490	3.604	2.752	0.852
0.692	1.601	3.684	2.721	0.963
0.737	1.703	3.700	2.695	1.005
0.786	1.816	3.756	2.668	1.088
0.833	1.924	3.841	2.644	1.197
0.879	2.031	3.866	2.622	1.244
0.923	2.133	3.935	2.601	1.334
0.971	2.244	4.093	2.581	1.512
1.017	2.350	4.208	2.563	1.645
1.061	2.452	4.200	2.547	1.653
1.110	2.565	4.212	2.529	1.683
1.153	2.665	4.238	2.514	1.724
1.199	2.772	4.374	2.500	1.874
1.244	2.874	4.507	2.486	2.021
1.292	2.986	4.764	2.471	2.293
1.338	3.091	5.057	2.459	2.598
1.380	3.189	5.336	2.447	2.889
1.428	3.299	5.593	2.434	3.159
1.472	3.402	5.776	2.423	3.353
1.524	3.521	5.915	2.411	3.504
1.566	3.619	6.040	2.401	3.639
1.659	3.834	6.090	2.381	3.709
1.748	4.040	6.074	2.362	3.712
1.842	4.254	5.902	2.343	3.559
1.936	4.474	5.773	2.327	3.446
2.027	4.683	5.563	2.311	3.252

$\frac{V}{(L)^{1/2}}$	N_R $\times 10$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$

PLATE V - Model 3878-1 Test 32 AA and 37 AA Results

DD 710 D.T.M.B MODEL 3878-1 L.B.P. 20.759 ft.

TEST 32 AA	TEST 37 AA Supp. 32 AA
TEMP. F.W. 63°F ν 1.1605×10^{-5}	TEMP. F.W. 63°F ν 1.1605×10^{-5}
$\frac{1.6889(L)^{3/2}}{\nu} = 2.3765 \times 10^{7}$	$\frac{1.6889(L)^{3/2}}{\nu} = 2.3765 \times 10^{7}$

Test 32 AA

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^{7}$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
0.658	0.906	4.284	2.982	1.302
0.716	0.985	4.276	2.941	1.335
0.768	1.057	4.296	2.908	1.388
0.821	1.130	4.317	2.877	1.440
0.876	1.205	4.376	2.847	1.529
0.933	1.284	4.459	2.818	1.641
0.992	1.365	4.562	2.790	1.772
1.045	1.438	4.767	2.768	1.999
1.097	1.510	4.865	2.746	2.119
1.157	1.592	4.865	2.723	2.142
1.209	1.665	4.989	2.704	2.285
1.262	1.737	5.210	2.687	2.523
1.319	1.816	5.558	2.668	2.890
1.367	1.882	5.917	2.653	3.264
1.429	1.967	6.238	2.635	3.603
1.482	2.039	6.425	2.620	3.805
1.536	2.115	6.623	2.605	4.018
1.589	2.187	6.702	2.592	4.110
1.644	2.263	6.737	2.578	4.159
1.701	2.341	6.698	2.565	4.133
1.756	2.417	6.647	2.552	4.095
1.811	2.492	6.565	2.541	4.024
1.861	2.562	6.491	2.530	3.961
1.918	2.640	6.381	2.518	3.863
1.975	2.719	6.274	2.507	3.767
2.028	2.792	6.175	2.497	3.678

Test 37 AA

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^{6}$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
0.549	7.554	3.992	3.073	0.919
0.571	7.856	4.185	3.053	1.132
0.601	8.278	4.214	3.026	1.188
0.637	8.763	4.257	2.998	1.259
0.691	9.517	4.204	2.958	1.246
0.768	10.574	4.269	2.908	1.361
0.790	10.877	4.294	2.894	1.400
0.843	11.602	4.377	2.864	1.513
0.900	12.388	4.387	2.834	1.553
0.955	13.143	4.536	2.808	1.728
0.988	13.597	4.602	2.792	1.810
1.023	14.080	4.723	2.777	1.946
1.080	14.865	4.799	2.753	1.946
1.185	16.315	4.943	2.713	2.230
1.209	16.646	5.013	2.704	2.309
2.090	28.763	6.076	2.485	3.591
2.140	29.458	6.006	2.476	3.530

PLATE VI - Model 3878-1 Test 33 WR and 35 BH Results

DD 710 D.T.M.B MODEL 3878-1 L.B.P. 20.759 ft.

TEST 33 WR TEST 35 BH

TEMP. F.W. 63ºF ν $1.1605\text{x}10^{-5}$ TEMP. F.W. 62.5ºF ν $1.1687\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.3765\text{x}10^{7} \qquad \frac{1.6889(L)^{3/2}}{\nu} = 2.3668\text{x}10^{7}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times10^{7}$	C_t $\times10^{-3}$	C_f $\times10^{-3}$	C_r $\times10^{-3}$
0.547	0.752	4.176	3.075	1.101
0.604	0.831	4.146	3.025	1.121
0.661	0.909	4.151	2.980	1.171
0.711	0.979	4.276	2.944	1.332
0.768	1.057	4.238	2.908	1.330
0.823	1.133	4.313	2.876	1.437
0.878	1.208	4.314	2.846	1.468
0.933	1.284	4.414	2.818	1.596
0.990	1.362	4.599	2.792	1.807
1.043	1.435	4.726	2.768	1.958
1.100	1.514	4.767	2.745	2.022
1.152	1.586	4.784	2.725	2.059
1.205	1.658	4.883	2.706	2.177
1.262	1.737	5.123	2.687	2.436
1.319	1.816	5.425	2.668	2.757
1.370	1.885	5.719	2.652	3.067
1.429	1.967	6.050	2.635	3.415
1.479	2.036	6.267	2.621	3.646
1.541	2.121	6.408	2.604	3.804
1.587	2.184	6.523	2.592	3.931
1.646	2.266	6.554	2.578	3.976
1.697	2.335	6.536	2.566	3.970
1.756	2.417	6.482	2.552	3.930
1.809	2.489	6.411	2.541	3.870
1.863	2.565	6.308	2.529	3.779
1.916	2.637	6.220	2.518	3.702
1.973	2.716	6.125	2.507	3.618
2.030	2.794	6.012	2.497	3.515
2.085	2.870	5.922	2.486	3.436

$\frac{V}{(L)^{1/2}}$	N_R $\times10^{7}$	C_t $\times10^{-3}$	C_f $\times10^{-3}$	C_r $\times10^{-3}$
0.549	0.750	3.858	3.076	0.782
0.604	0.825	3.839	3.028	0.811
0.658	0.900	3.914	2.985	0.929
0.713	0.975	3.968	2.946	1.022
0.768	1.050	3.982	2.911	1.071
0.821	1.122	4.091	2.880	1.211
0.878	1.200	4.122	2.849	1.273
0.933	1.275	4.191	2.822	1.369
0.990	1.353	4.364	2.795	1.569
1.043	1.425	4.524	2.772	1.752
1.100	1.503	4.530	2.748	1.782
1.152	1.575	4.524	2.728	1.796
1.209	1.653	4.668	2.707	1.961
1.264	1.728	4.881	2.689	2.192
1.321	1.806	5.235	2.670	2.565
1.370	1.872	5.576	2.655	2.921
1.429	1.953	5.847	2.637	3.210
1.482	2.025	6.106	2.623	3.483
1.536	2.100	6.218	2.608	3.610
1.591	2.175	6.300	2.594	3.706
1.646	2.250	6.322	2.580	3.742
1.701	2.325	6.324	2.568	3.756
1.756	2.400	6.249	2.555	3.694
1.811	2.475	6.180	2.543	3.637
1.863	2.547	6.082	2.532	3.550
1.916	2.619	5.998	2.521	3.477
1.975	2.700	5.888	2.509	3.379
2.028	2.772	5.787	2.500	3.287
2.085	2.850	5.675	2.489	3.186

PLATE VII - Model 4007 Test 2 AA and 3 WR Results

DD 710 D.T.M.B MODEL 4007 L.B.P. 12.00 ft.

TEST 2 AA

TEMP. F.W. 63°F ν 1.1605×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 6.0496\times10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times10^{6}$	$C_t \times10^{-3}$	$C_f \times10^{-3}$	$C_r \times10^{-3}$
0.433	2.619	4.815	3.688	1.127
0.505	3.056	4.852	3.588	1.264
0.577	3.492	4.715	3.505	1.210
0.650	3.929	4.718	3.433	1.285
0.722	4.366	4.686	3.371	1.315
0.794	4.802	4.804	3.317	1.487
0.866	5.239	4.771	3.268	1.503
0.941	5.693	4.851	3.222	1.629
1.013	6.129	5.065	3.182	1.883
1.082	6.549	5.137	3.147	1.990
1.155	6.985	5.204	3.113	2.091
1.230	7.439	5.406	3.080	2.326
1.299	7.858	5.895	3.053	2.842
1.377	8.330	6.350	3.023	3.327
1.449	8.766	6.760	2.998	3.762
1.521	9.203	7.037	2.974	4.063
1.593	9.639	7.151	2.952	4.199
1.663	10.059	7.190	2.932	4.258
1.735	10.495	7.116	2.911	4.205
1.804	10.915	7.048	2.892	4.156
1.882	11.386	6.890	2.874	4.016
1.951	11.805	6.770	2.857	3.913
2.029	12.277	6.601	2.839	3.762
2.095	12.678	6.486	2.824	3.662
2.165	13.097	6.388	2.809	3.579

TEST 3 WR

TEMP. F.W. 63°F ν 1.1605×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 6.0496\times10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times10^{6}$	$C_t \times10^{-3}$	$C_f \times10^{-3}$	$C_r \times10^{-3}$
0.433	2.619	4.803	3.668	1.115
0.502	3.039	4.912	3.592	1.320
0.577	3.492	4.690	3.505	1.185
0.650	3.929	4.755	3.433	1.322
0.722	4.366	4.600	3.371	1.229
0.797	4.820	4.736	3.314	1.422
0.869	5.256	4.704	3.265	1.439
0.941	5.693	4.776	3.222	1.554
1.010	6.112	5.010	3.184	1.826
1.082	6.549	5.134	3.147	1.987
1.108	6.706	5.115	3.134	1.981
1.155	6.985	5.085	3.113	1.972
1.230	7.439	5.314	3.080	2.234
1.299	7.858	5.747	3.053	2.694
1.374	8.313	6.191	3.025	3.166
1.443	8.732	6.622	3.000	3.622
1.518	9.186	6.846	2.975	3.871
1.591	9.622	6.985	2.953	4.032
1.663	10.059	6.987	2.932	4.055
1.735	10.495	6.977	2.911	4.066
1.804	10.915	6.859	2.892	3.967
1.876	11.351	6.761	2.875	3.886
1.951	11.805	6.581	2.857	3.724
2.026	12.260	6.450	2.839	3.611
2.096	12.678	6.321	2.824	3.497
2.162	13.080	6.179	2.810	3.369

PLATE VIII - Model 4007 Test 5 BH and 6 BH Results

DD 710 D.T.M.B MODEL 4007 L.B.P. 12.00 ft.

TEST 5 & 6 B.H. TEST ______

TEMP. F.W. 63°F ν 1.1605×10^{-5} TEMP. F.W. _____ ν _________

$$\frac{1.6889(L)^{3/2}}{\nu} = 6.0496 \times 10^{6} \qquad \frac{1.6889(L)^{3/2}}{\nu} = \_\_\_\_\_\_$$

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^6$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
0.432	2.611	4.369	3.690	0.679
0.502	3.039	4.374	3.592	0.782
0.531	3.214	4.270	3.556	0.714
0.574	3.475	4.325	3.508	0.817
0.577	3.492	4.231	3.505	0.726
0.650	3.929	4.150	3.433	0.717
0.722	4.366	4.339	3.371	0.968
0.797	4.820	4.335	3.314	1.021
0.866	5.239	4.418	3.268	1.150
0.938	5.676	4.499	3.223	1.276
0.982	5.938	4.621	3.199	1.422
1.010	6.112	4.727	3.184	1.543
1.054	6.374	4.791	3.161	1.630
1.083	6.549	4.800	3.147	1.653
1.152	6.968	4.867	3.114	1.753
1.155	6.985	4.779	3.113	1.666
1.204	7.282	4.842	3.092	1.750
1.227	7.422	5.053	3.082	1.953
1.301	7.868	5.444	3.052	2.392
1.377	8.330	5.960	3.023	2.937
1.417	8.575	6.258	3.009	3.249
1.443	8.732	6.386	3.000	3.386
1.446	8.749	6.377	2.999	3.378
1.516	9.168	6.614	2.976	3.638
1.585	9.587	6.711	2.954	3.757
1.666	10.076	6.737	2.931	3.806
1.735	10.495	6.718	2.911	3.807
1.738	10.513	6.695	2.910	3.785
1.804	10.915	6.572	2.892	3.680
1.874	11.334	6.472	2.876	3.596
1.949	11.788	6.337	2.857	3.480
2.021	12.224	6.213	2.840	3.373
2.024	12.242	6.203	2.840	3.363
2.093	12.661	6.056	2.825	3.231
2.165	13.097	5.926	2.809	3.117

$\frac{V}{(L)^{1/2}}$	$N_R \times 10$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$

PLATE IX - Model 4507 Test 1 AA and 2 AA Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 1 AA

TEMP. F.W. 74°F ν $1.0018\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.6062\text{x}10^{6}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times10^{6}$	C_t $\times10^{-3}$	C_f $\times10^{-3}$	C_r $\times10^{-3}$
1.046	1.679	6.317	3.998	2.319
1.054	1.693	6.238	3.993	2.245
1.057	1.698	6.192	3.991	2.201
1.179	1.894	6.352	3.911	2.441
1.182	1.898	6.340	3.910	2.430
1.254	2.014	6.630	3.867	2.763
1.254	2.014	6.644	3.867	2.777
1.361	2.186	7.509	3.810	3.699
1.367	2.196	7.436	3.807	3.629
1.446	2.323	8.168	3.768	4.400
1.451	2.330	8.104	3.766	4.338
1.456	2.338	8.103	3.764	4.339
1.643	2.639	8.575	3.683	4.892
1.644	2.641	8.564	3.683	4.881
1.785	2.866	8.288	3.629	4.659
1.812	2.911	8.158	3.619	4.539
1.912	3.072	8.138	3.585	4.553
1.915	3.076	8.108	3.584	4.524
1.921	3.086	8.063	3.582	4.481

TEST 2 AA

TEMP. F.W. 78°F ν $0.95276\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.6888\text{x}10^{6}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times10^{6}$	C_t $\times10^{-3}$	C_f $\times10^{-3}$	C_r $\times10^{-3}$
0.399	6.746	5.860	4.762	1.098
0.401	6.765	5.726	4.760	0.966
0.590	9.960	6.233	4.413	1.820
0.591	9.975	6.325	4.411	1.914
0.591	9.978	6.188	4.411	1.777
0.715	12.078	5.854	4.253	1.601
1.447	24.439	7.878	3.734	4.144
1.552	26.205	8.295	3.688	4.607
1.715	28.960	8.318	3.622	4.696
1.982	33.482	7.756	3.530	4.226
1.986	33.541	7.729	3.530	4.199

PLATE X - Model 4507 Test 3 AA and 4 AA Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 3 AA

TEMP. F.W. 73.7ºF ν 1.0057×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.5999 \times 10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^6$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
0.604	0.967	5.960	4.438	1.522
0.606	0.970	5.979	4.435	1.544
0.609	0.974	5.933	4.432	1.501
0.721	1.154	5.960	4.290	1.670
0.722	1.155	5.949	4.290	1.659
0.728	1.164	5.927	4.283	1.644
1.148	1.837	6.255	3.933	2.322
1.149	1.838	6.249	3.933	2.316
1.149	1.839	6.260	3.933	2.327
1.302	2.083	6.924	3.843	3.081
1.304	2.086	6.882	3.842	3.040
1.308	2.093	6.860	3.840	3.020
1.309	2.094	6.869	3.840	3.029
1.537	2.459	8.346	3.730	4.616
1.539	2.462	8.305	3.729	4.576
1.650	2.640	8.392	3.683	4.709
1.653	2.644	8.374	3.682	4.692

TEST 4 AA

TEMP. F.W. 76ºF ν 0.97990×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.6421 \times 10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^6$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
1.161	1.907	6.279	3.906	2.376
1.162	1.908	6.293	3.906	2.387
1.200	1.970	6.324	3.883	2.441
1.202	1.973	6.330	3.882	2.448
1.227	2.015	6.472	3.867	2.605
1.229	2.018	6.466	3.866	2.600
1.253	2.058	6.610	3.852	2.758
1.256	2.062	6.651	3.850	2.801
1.281	2.104	6.748	3.836	2.912
1.553	2.551	8.288	3.706	4.582
1.553	2.551	8.318	3.706	4.612
1.567	2.573	8.352	3.699	4.653
1.567	2.573	8.408	3.699	4.709
1.601	2.628	8.409	3.686	4.723
1.607	2.640	8.342	3.683	4.659
1.639	2.691	8.381	3.670	4.711
1.688	2.771	8.363	3.651	4.712
1.719	2.822	8.359	3.639	4.720
1.719	2.822	8.356	3.639	4.717
1.720	2.824	8.344	3.639	4.705
1.773	2.911	8.256	3.619	4.637
1.775	2.915	8.255	3.618	4.637
1.778	2.915	8.227	3.618	4.609
1.825	2.998	8.182	3.600	4.582
1.828	3.002	8.170	3.600	4.570
1.970	3.235	7.830	3.552	4.278
1.974	3.241	7.812	3.551	4.261
2.059	3.382	7.646	3.525	4.121
2.062	3.386	7.638	3.524	4.114

PLATE XI - Model 4507 Test 5 AA Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 5 AA

TEMP. F.W. 73.1°F ν $1.0134\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.5878\text{x}10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^6$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
0.479	0.761	6.445	4.650	1.795
0.481	0.763	6.457	4.648	1.809
0.491	0.779	6.380	4.629	1.751
0.517	0.822	6.440	4.580	1.860
0.526	0.836	6.373	4.565	1.808
0.534	0.848	6.286	4.552	1.734
0.548	0.870	6.311	4.530	1.781
0.568	0.902	6.295	4.498	1.797
0.585	0.928	6.249	4.473	1.776
0.593	0.941	6.125	4.461	1.664
0.600	0.953	6.098	4.451	1.647
0.626	0.994	6.146	4.414	1.732
0.633	1.005	6.113	4.405	1.708
0.675	1.072	6.050	4.351	1.699
0.703	1.117	6.109	4.317	1.792
0.708	1.123	6.017	4.313	1.704
0.719	1.142	5.907	4.299	1.608
0.729	1.157	5.907	4.288	1.619
0.730	1.159	5.906	4.287	1.619
0.735	1.167	5.872	4.281	1.591
0.756	1.201	5.914	4.257	1.657
0.769	1.221	5.866	4.244	1.622
0.773	1.227	5.845	4.240	1.605
0.804	1.277	5.749	4.209	1.540
0.804	1.277	5.831	4.209	1.622
0.828	1.315	5.883	4.185	1.698
0.834	1.325	5.817	4.179	1.638
0.836	1.327	5.898	4.178	1.720
0.868	1.378	5.892	4.149	1.743
0.899	1.427	5.883	4.121	1.762

TEST 5 AA (cont'd)

TEMP. F.W. 73.1°F ν $1.0134\text{x}10^{-5}$

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.5878\text{x}10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^6$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
0.913	1.449	5.976	4.109	1.867
0.944	1.499	5.985	4.083	1.902
0.945	1.500	5.966	4.083	1.883
0.963	1.529	6.055	4.068	1.987
0.964	1.530	6.087	4.068	2.019
0.984	1.563	6.102	4.053	2.049
0.986	1.566	6.066	4.052	2.014
1.012	1.607	6.132	4.032	2.100
1.012	1.606	6.109	4.032	2.077
1.028	1.632	6.180	4.020	2.160
1.034	1.641	6.165	4.016	2.149
1.049	1.666	6.213	4.005	2.208
1.085	1.722	6.188	3.980	2.208
1.089	1.729	6.196	3.977	2.219
1.124	1.784	6.222	3.955	2.267
1.126	1.788	6.202	3.953	2.249
1.247	1.980	6.659	3.879	2.780
1.252	1.988	6.625	3.876	2.749
1.307	2.075	6.885	3.846	3.039
1.329	2.111	7.204	3.834	3.370
1.332	2.115	7.191	3.833	3.358
1.352	2.147	7.424	3.823	3.601
1.403	2.228	7.744	3.797	3.947
1.449	2.300	7.960	3.775	4.185
1.449	2.300	7.960	3.775	4.185
1.451	2.304	7.996	3.774	4.222
1.485	2.358	8.189	3.758	4.431
1.485	2.358	8.173	3.754	4.419

PLATE XII - Model 4507 Test 7 WR Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 7 WR

TEMP. F.W. 70oF ν 1.0552×10^{-5}

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.5249\times10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times10^{6}$	$C_t \times10^{-3}$	$C_f \times10^{-3}$	$C_r \times10^{-3}$
0.438	0.668	6.216	4.771	1.445
0.452	0.689	6.196	4.742	1.454
0.506	0.772	6.126	4.637	1.489
0.563	0.859	5.959	4.541	1.418
0.566	0.863	5.933	4.537	1.396
0.658	1.003	5.790	4.407	1.383
0.661	1.008	5.751	4.403	1.348
0.745	1.136	5.662	4.303	1.359
0.811	1.237	5.701	4.234	1.467
0.822	1.253	5.603	4.224	1.379
0.889	1.356	5.656	4.161	1.495
0.942	1.436	5.681	4.117	1.564
0.991	1.511	5.826	4.078	1.748
1.031	1.572	5.977	4.048	1.929
1.054	1.607	6.035	4.032	2.003
1.056	1.610	5.992	4.030	1.962
1.103	1.682	6.037	3.997	2.040
1.104	1.683	5.991	3.997	1.994
1.138	1.735	6.114	3.976	2.138
1.139	1.737	6.118	3.974	2.144
1.186	1.808	6.190	3.945	2.245
1.188	1.812	6.192	3.943	2.249
1.224	1.866	6.352	3.922	2.430
1.232	1.879	6.331	3.916	2.415
1.266	1.930	6.585	3.898	2.687
1.308	1.994	6.897	3.874	3.023
1.313	2.002	6.866	3.871	2.995
1.374	2.095	7.346	3.840	3.506

TEST 7 WR (Cont'd)

TEMP. F.W. 73oF ν 1.0552×10^{6}

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.5249\times10^{6}$$

$\frac{V}{(L)^{1/2}}$	$N_R \times10^{6}$	$C_t \times10^{-3}$	$C_f \times10^{-3}$	$C_r \times10^{-3}$
1.414	2.156	7.489	3.820	3.669
1.438	2.193	7.784	3.808	3.976
1.440	2.196	7.769	3.807	3.962
1.446	2.205	7.725	3.804	3.921
1.476	2.251	7.948	3.790	4.158
1.480	2.257	7.887	3.788	4.099
1.488	2.269	7.968	3.784	4.184
1.530	2.333	8.001	3.765	4.236
1.544	2.354	8.070	3.759	4.311
1.545	2.356	8.088	3.759	4.329
1.546	2.357	8.092	3.759	4.333
1.581	2.411	8.087	3.743	4.344
1.587	2.420	8.075	3.741	4.334
1.590	2.424	8.046	3.740	4.306
1.621	2.472	8.118	3.726	4.392
1.631	2.487	8.119	3.723	4.396
1.666	2.540	8.100	3.708	4.392
1.667	2.542	8.136	3.708	4.428
1.700	2.592	8.127	3.695	4.432
1.707	2.603	8.092	2.692	4.400
1.770	2.699	7.989	3.668	4.321
1.772	2.702	8.017	3.686	4.331
1.841	2.807	7.882	3.642	4.240
1.854	2.827	7.796	3.639	4.157
1.918	2.925	7.703	3.616	4.087
1.999	3.048	7.506	3.589	3.917
2.095	3.195	7.337	3.560	3.777
2.108	3.214	7.271	3.556	3.715

PLATE XIII - Model 4507 Test 8 WR and 11 WR Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 8 WR

TEMP. F.W. 73°F v 1.0147x10^{-5}

$$\frac{1.6889(L)^{3/2}}{v} = 1.5857\text{x}10^{6}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^6$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.486	0.771	6.022	4.638	1.384
0.499	0.791	5.919	4.615	1.304
0.542	0.859	5.903	4.541	1.362
0.547	0.867	5.840	4.533	1.307
0.596	0.945	5.856	4.458	1.398
0.597	0.947	5.851	4.456	1.395
0.622	0.986	5.707	4.421	1.286
0.663	1.051	5.685	4.368	1.317
0.705	1.118	5.730	4.316	1.414
0.738	1.170	5.655	4.279	1.376
0.739	1.172	5.638	4.278	1.360
0.777	1.232	5.654	4.237	1.417
0.813	1.289	5.706	4.201	1.505
0.814	1.291	5.706	4.200	1.506
0.851	1.349	5.746	4.165	1.581
0.852	1.351	5.721	4.165	1.555
1.005	1.594	5.970	4.037	1.933
1.008	1.598	5.996	3.991	2.005
1.296	2.055	6.676	3.853	2.823
1.296	2.055	6.676	3.853	2.823
1.355	2.149	7.016	3.822	3.194
1.357	2.152	7.019	3.821	3.198
2.069	3.281	7.338	3.544	3.794
2.069	3.281	7.351	3.544	3.807

TEST 11 WR

TEMP. F.W. 73°F v 1.0147x10^{-5}

$$\frac{1.6889(L)^{3/2}}{v} = 1.5857\text{x}10^{5}$$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^6$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.538	0.853	5.834	4.547	1.287
0.539	0.855	5.808	4.545	1.263
0.577	0.915	5.909	4.486	1.423
0.579	0.918	5.753	4.483	1.270
0.721	1.143	5.710	4.305	1.405
0.773	1.226	5.512	4.241	1.271
0.774	1.227	5.589	4.240	1.349
0.787	1.248	5.747	4.227	1.520
0.806	1.278	5.481	4.208	1.273
0.828	1.313	5.507	4.186	1.321
0.831	1.318	5.588	4.183	1.405
0.836	1.326	5.508	4.178	1.330
0.839	1.330	5.580	4.176	1.404
0.849	1.346	5.629	4.167	1.462
0.856	1.357	5.606	4.161	1.445
0.857	1.359	5.737	4.160	1.577
0.895	1.419	5.656	4.126	1.530
0.897	1.422	5.684	4.124	1.560
0.898	1.424	5.796	4.123	1.673
0.929	1.473	5.631	4.097	1.534
0.931	1.476	5.701	4.096	1.605
0.932	1.478	5.567	4.095	1.472

PLATE XIV - Model 4507 Test 9 BH Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 9 BH TEST _____

TEMP. F.W. 75°F v 0.98918×10^{-5} TEMP. F.W. _____ v _________

$$\frac{1.6889(L)^{3/2}}{v} = 1.6267 \times 10^{6} \qquad \frac{1.6889(L)^{3/2}}{v} = \_\_\_\_\_\_$$

$\frac{V}{(L)^{1/2}}$	$N_R \times 10^6$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$
1.457	2.370	7.294	3.755	3.539
1.458	2.372	7.291	3.754	3.537
1.488	2.420	7.439	3.741	3.698
1.489	2.422	7.418	3.740	3.678
1.516	2.466	7.575	3.728	3.847
1.518	2.469	7.536	3.727	3.809
1.524	2.479	7.533	3.724	3.809
1.551	2.523	7.620	3.713	3.907
1.559	2.536	7.583	3.709	3.874
1.586	2.580	7.652	3.698	3.954
1.586	2.580	7.656	3.698	3.958
1.622	2.638	7.709	3.683	4.026
1.623	2.640	7.665	3.683	3.982
1.625	2.643	7.694	3.682	4.012
1.655	2.692	7.651	3.670	3.981
1.670	2.716	7.614	3.664	3.950
1.724	2.804	7.615	3.643	3.972
1.732	2.817	7.547	3.641	3.906
1.801	2.930	7.451	3.615	3.836
1.802	2.931	7.448	3.615	3.833
1.876	3.052	7.354	3.589	3.765
1.881	3.061	7.300	3.587	3.713
1.971	3.206	7.141	3.558	3.583
1.974	3.211	7.153	3.557	3.596
2.069	3.366	6.936	3.528	3.408
2.074	3.374	6.931	3.526	3.405

$\frac{V}{(L)^{1/2}}$	$N_R \times 10$	$C_t \times 10^{-3}$	$C_f \times 10^{-3}$	$C_r \times 10^{-3}$

PLATE XV - Model 4507 Test 10 BH Results

DD 710 D.T.M.B MODEL 4507 L.B.P. 4.494 ft.

TEST 10 BH	TEST 10 BH (Cont'd)
TEMP. F.W. 73ºF ν $1.0147\text{x}10^{-5}$	TEMP. F.W. 73ºF ν $1.0147\text{x}10^{6}$
$\frac{1.6889(L)^{3/2}}{\nu}$ = $1.5857\text{x}10^{6}$	$\frac{1.6889(L)^{3/2}}{\nu}$ = $1.5857\text{x}10^{6}$

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^{6}$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.457	0.725	5.426	4.694	0.732
0.467	0.740	5.363	4.676	0.687
0.484	0.767	5.393	4.643	0.750
0.503	0.798	5.371	4.607	0.764
0.526	0.834	5.387	4.567	0.820
0.545	0.864	5.305	4.536	0.769
0.567	0.899	5.307	4.501	0.806
0.578	0.916	5.305	4.485	0.820
0.584	0.926	5.365	4.475	0.890
0.601	0.953	5.300	4.451	0.849
0.632	1.002	5.308	4.407	0.901
0.634	1.005	5.230	4.405	0.825
0.674	1.069	5.196	4.353	0.843
0.695	1.102	5.131	4.329	0.802
0.696	1.104	5.194	4.327	0.867
0.739	1.172	5.116	4.277	0.839
0.739	1.172	5.175	4.277	0.898
0.775	1.229	5.132	4.238	0.894
0.778	1.234	5.109	4.235	0.874
0.778	1.234	5.107	4.235	0.872
0.809	1.283	5.215	4.205	1.010
0.813	1.289	5.225	4.200	1.025
0.838	1.329	5.256	4.176	1.080
0.840	1.332	5.239	4.175	1.064
0.882	1.398	5.258	4.137	1.121
0.883	1.400	5.235	4.136	1.099
0.948	1.503	5.306	4.081	1.225

$\frac{V}{(L)^{1/2}}$	N_R $\times 10^{6}$	C_t $\times 10^{-3}$	C_f $\times 10^{-3}$	C_r $\times 10^{-3}$
0.952	1.510	5.286	4.078	1.208
0.994	1.576	5.508	4.046	1.462
0.995	1.578	5.520	4.045	1.475
1.033	1.638	5.649	4.017	1.632
1.033	1.638	5.663	4.017	1.646
1.087	1.724	5.694	3.979	1.715
1.092	1.732	5.677	3.976	1.701
1.131	1.793	5.676	3.950	1.726
1.140	1.808	5.666	3.945	1.721
1.205	1.911	5.744	3.905	1.839
1.210	1.919	5.738	3.901	1.837
1.250	1.982	5.934	3.878	2.056
1.251	1.984	5.933	4.878	2.055
1.300	2.061	6.233	3.851	2.382
1.302	2.064	6.246	3.850	2.396
1.341	2.126	6.559	3.829	2.730
1.342	2.128	6.564	3.829	2.735
1.384	2.195	3.863	3.808	3.055
1.386	2.198	6.846	3.807	3.039
1.422	2.255	7.129	3.788	3.341
1.423	2.256	7.164	3.788	3.376
1.426	2.261	7.143	3.787	3.356
1.451	2.310	7.295	3.772	3.523
1.545	2.450	7.538	3.732	3.806
1.547	2.453	7.560	3.731	3.829
1.817	2.881	7.407	3.626	3.781

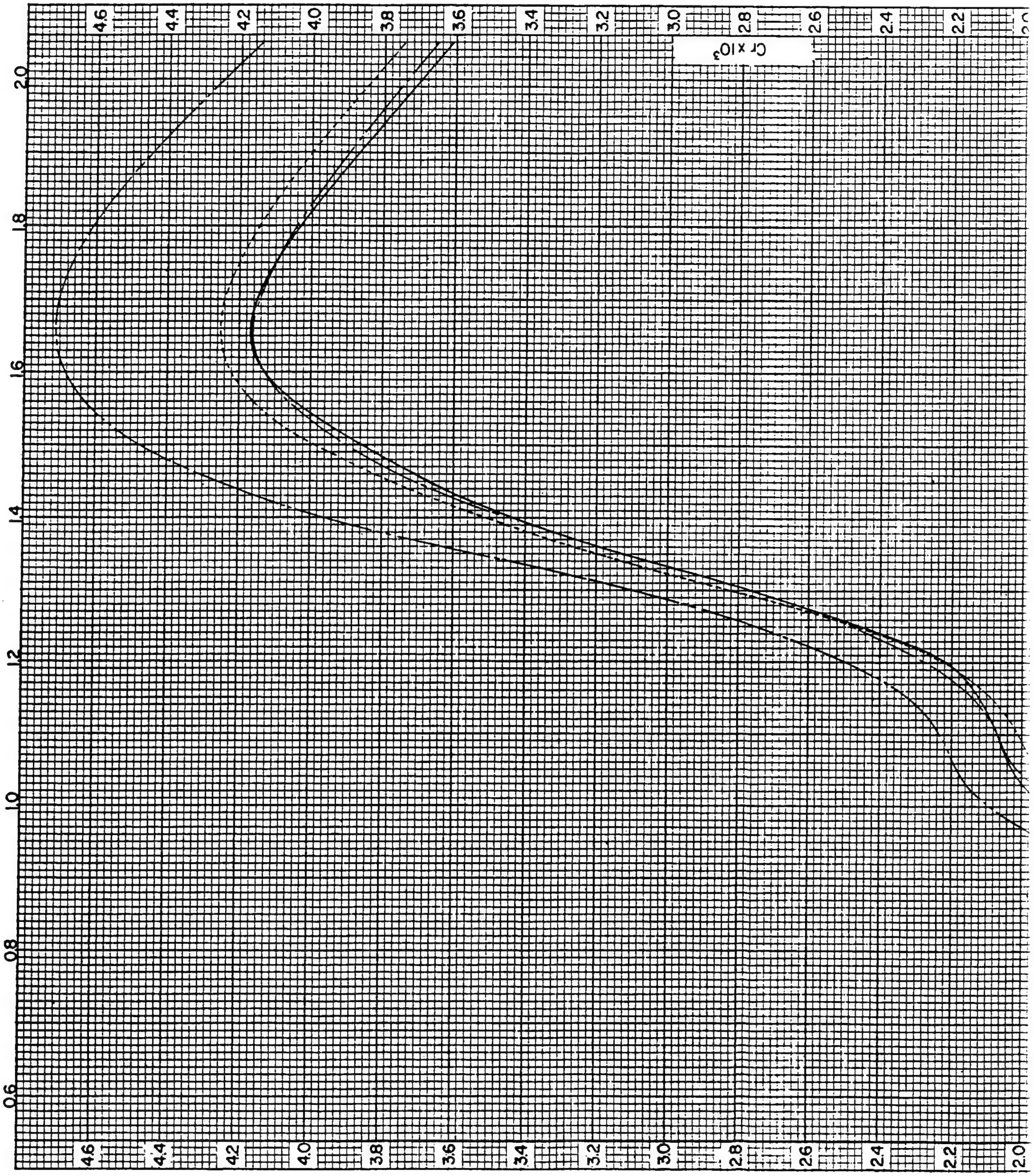
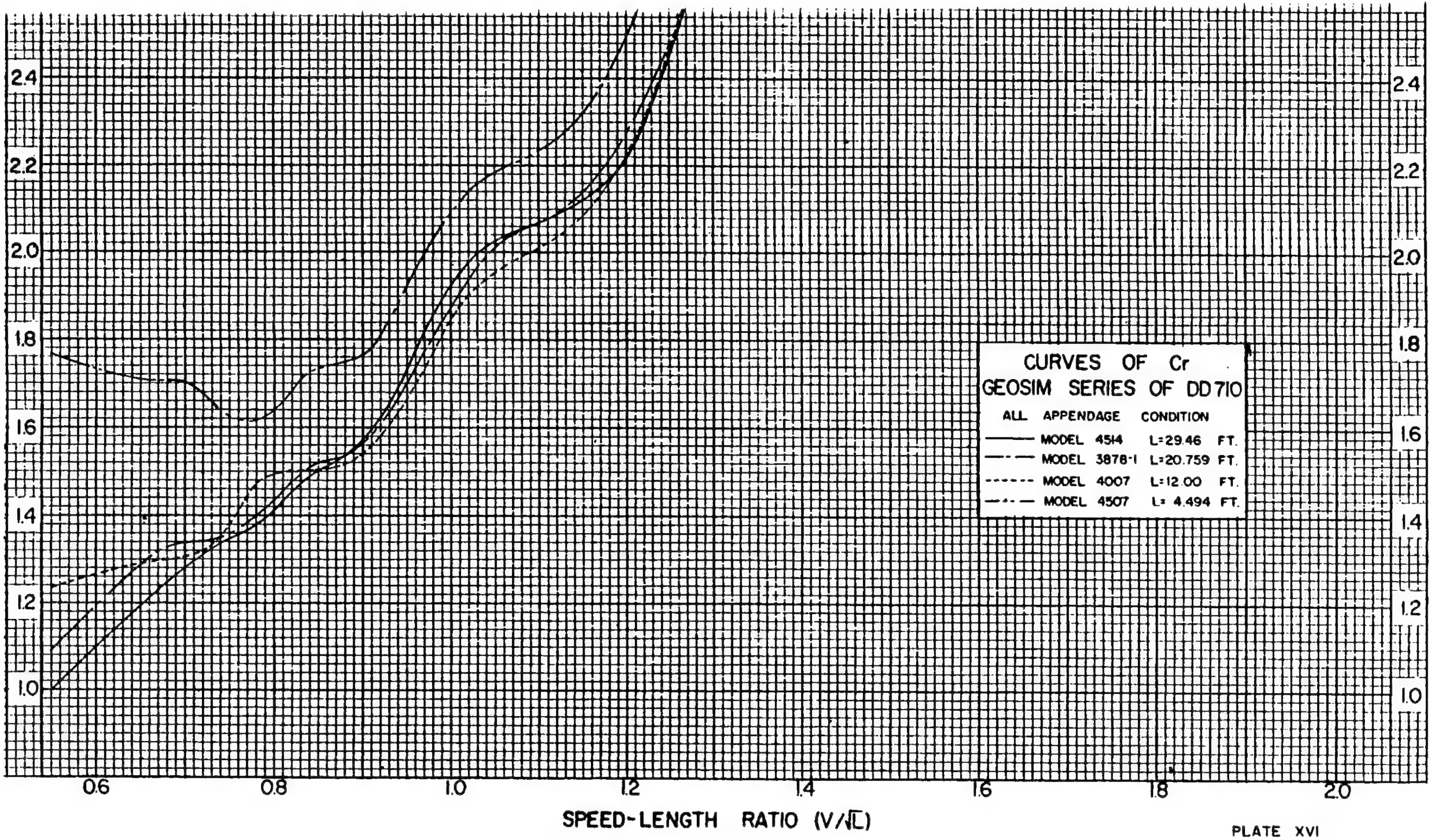


PLATE XVII - Curves of C_r Geosim Series of DD710 All Appendage Condition



CURVES OF Cr
GEOSIM SERIES OF DD710
ALL APPENDAGE CONDITION
MODEL 4514 L=29.46 FT.
MODEL 3878-1 L=20.759 FT.
MODEL 4007 L=12.00 FT.
MODEL 4507 L= 4.494 FT.
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
SPEED-LENGTH RATIO (V/√L)

PLATE XVI

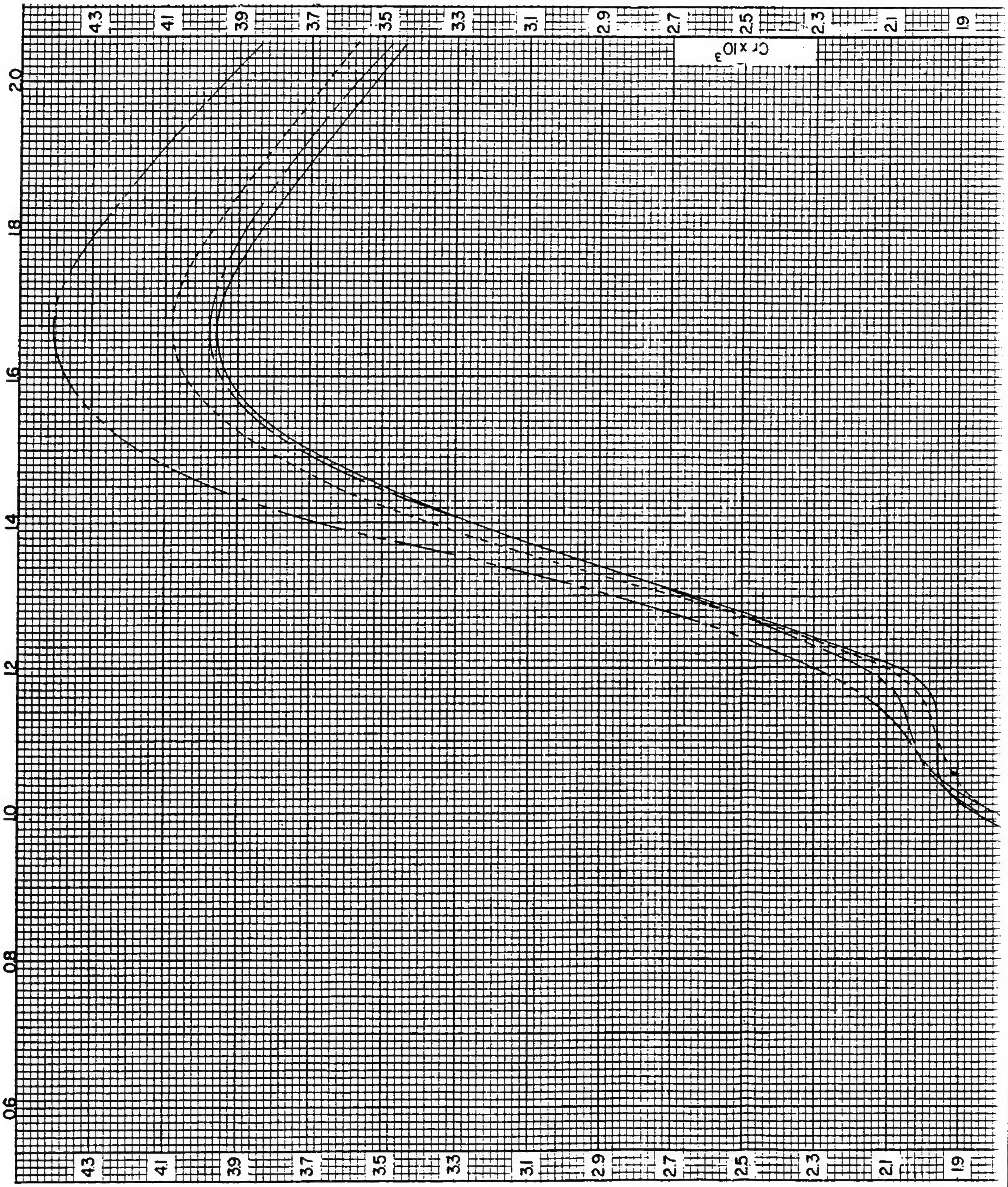
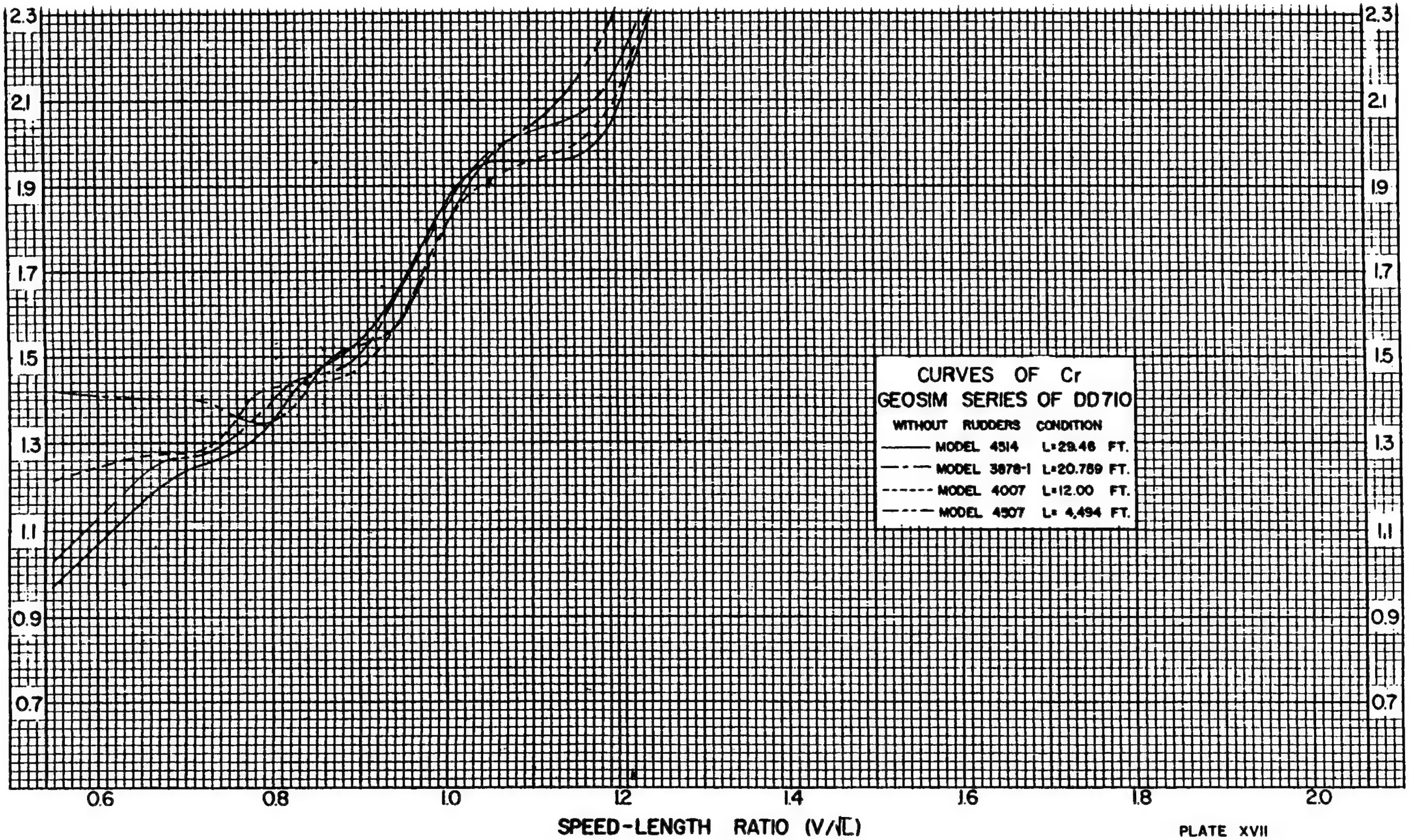


PLATE XVII - Curves of C_r Geosim Series of DD710 Without Rudders Condition



CURVES OF Cr
GEOSIM SERIES OF DD710
WITHOUT RUDDERS CONDITION
MODEL 4514 L=29.46 FT.
MODEL 3876-1 L=20.789 FT.
MODEL 4007 L=12.00 FT.
MODEL 4507 L= 4.494 FT.
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
SPEED-LENGTH RATIO (V/√L)

PLATE XVII

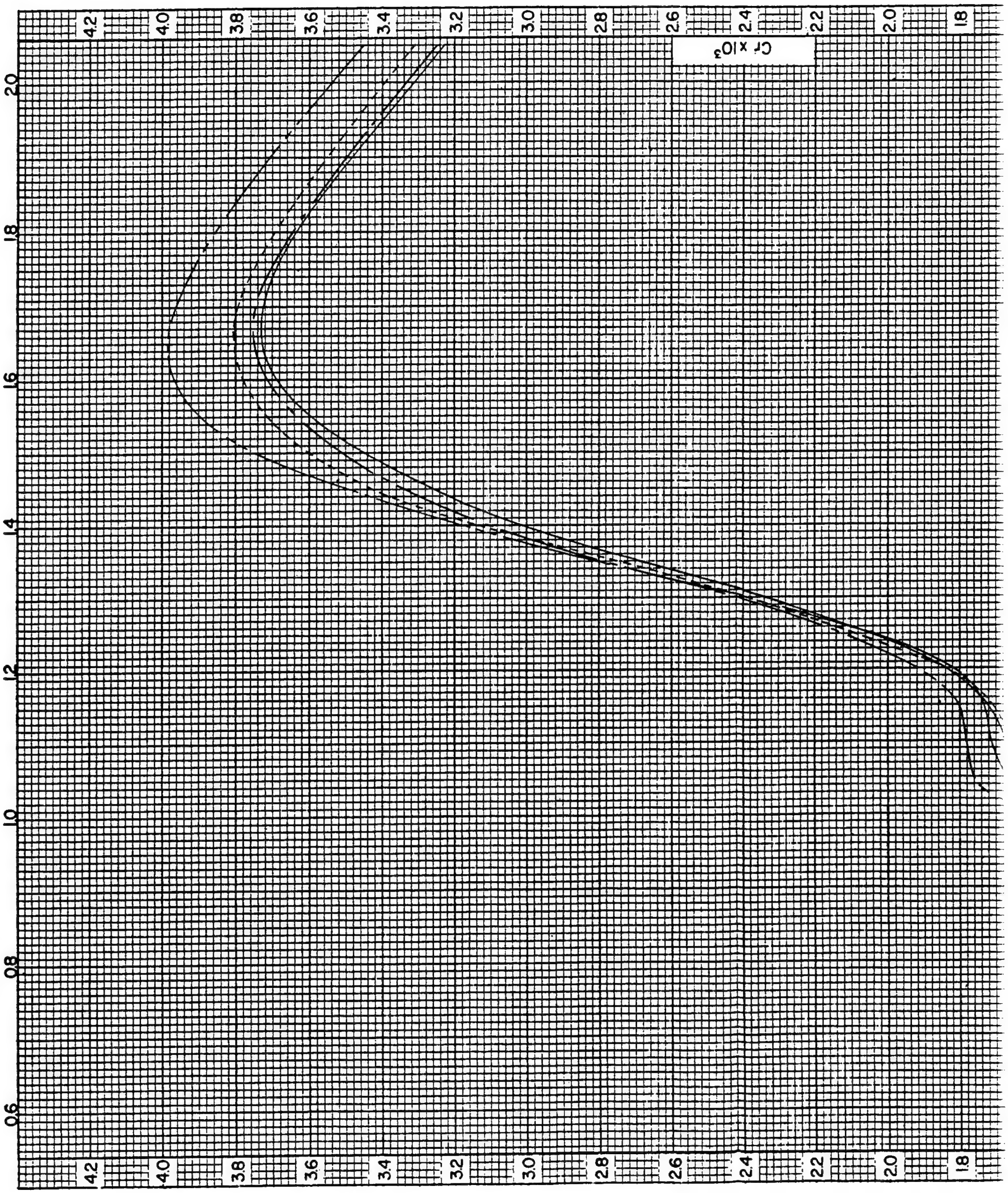


PLATE XVIII - Curves of C_r Geosim Series of DD710 Bare Hull Condition

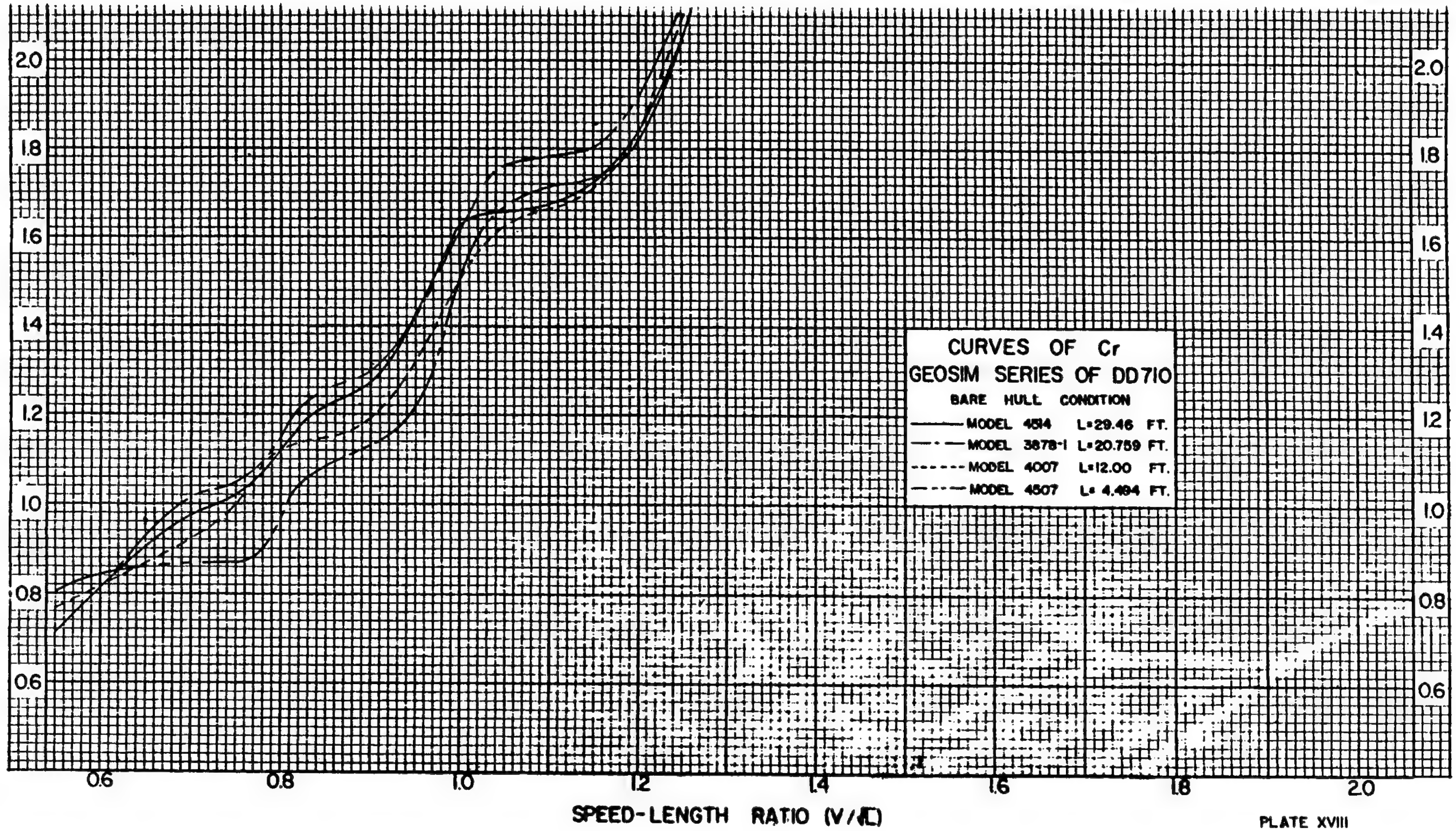

CURVES OF Cr
GEOSIM SERIES OF DD710
BARE HULL CONDITION
MODEL 4514 L=29.46 FT.
MODEL 3878-1 L=20.759 FT.
MODEL 4007 L=12.00 FT.
MODEL 4507 L= 4.494 FT.
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
SPEED-LENGTH RATIO (V/√L)

PLATE XVIII

PLATE XIX - MODEL 4514 DATA CALCULATION SHEET

MODEL 4514 SHIP DD 710

LBP 29.46 ft. $\nu = 1.2817 \times 10^{-5}$ LBP 383.0 FT

$$\frac{1.6889(L)^{3/2}}{\nu} = 2.1070 \times 10^{7} \qquad \frac{1.6889(L)^{3/2}}{\nu} = 9.8768 \times 10^{8}$$

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$V/\sqrt{L}$	$\times 10^{7}$ N_R MODEL	$Log10$ N_R	C_{rAA}*	C_{rWR}*	C_{rBH}*	ΔC_r* RUD	ΔC_r* S&S	$\times 10^{9}$ N_R SHIP	C_f* SHIP	C_{tBH}* SHIP	% RUD	% S&S	% TOT
0.55	1.159	7.064	.995	.967	.736	.028	.231	0.543	1.653	2.389	1.2	9.8	11.0
0.60	1.264	7.102	1.097	1.070	.825	.027	.245	0.593	1.634	2.459	1.1	10.0	11.1
0.65	1.370	7.137	1.190	1.161	.908	.029	.253	0.642	1.618	2.526	1.2	10.1	11.3
0.70	1.475	7.169	1.276	1.234	.972	.042	.262	0.691	1.603	2.575	1.6	10.3	11.9
0.75	1.580	7.199	1.343	1.269	1.019	.074	.250	0.741	1.589	2.608	2.9	9.7	12.6
0.80	1.686	7.227	1.408	1.348	1.122	.060	.226	0.790	1.576	2.698	2.2	8.4	10.6
0.85	1.791	7.253	1.497	1.465	1.218	.032	.247	0.840	1.564	2.782	1.2	9.0	10.2
0.90	1.896	7.278	1.570	1.534	1.273	.036	.261	0.889	1.553	2.826	1.3	9.3	10.6
0.95	2.002	7.302	1.729	1.667	1.430	.062	.237	0.938	1.543	2.973	2.1	8.0	10.1
1.00	2.107	7.324	1.921	1.849	1.625	.072	.224	0.988	1.533	3.158	2.3	7.2	9.5
1.05	2.212	7.345	2.023	1.953	1.654	.070	.299	1.037	1.524	3.178	2.2	9.5	11.7
1.10	2.318	7.365	2.063	1.960	1.671	.103	.289	1.086	1.516	3.187	3.2	9.1	12.3
1.15	2.423	7.384	2.121	1.965	1.721	.156	.244	1.136	1.507	3.228	4.9	7.6	12.5
1.20	2.528	7.403	2.216	2.062	1.838	.154	.224	1.185	1.500	3.338	4.6	6.8	11.4
1.25	2.634	7.421	2.446	2.329	2.049	.117	.280	1.235	1.492	3.541	3.3	8.0	11.3
1.30	2.739	7.438	2.752	2.625	2.339	.127	.314	1.284	1.485	3.824	3.3	8.3	11.6
1.35	2.844	7.454	3.114	2.952	2.679	.162	.273	1.333	1.478	4.157	3.9	6.6	10.5
1.40	2.950	7.470	3.425	3.250	3.010	.175	.240	1.383	1.472	4.482	3.9	5.4	9.3
1.45	3.055	7.485	3.668	3.493	3.258	.175	.235	1.432	1.466	4.724	3.7	5.0	8.7
1.50	3.160	7.500	3.853	3.697	3.445	.156	.252	1.482	1.459	4.904	3.2	5.2	8.4
1.55	3.266	7.514	4.014	3.846	3.594	.168	.252	1.531	1.454	5.048	3.3	5.0	8.3
1.60	3.371	7.528	4.125	3.928	3.686	.197	.242	1.580	1.448	5.134	3.8	4.7	8.5
1.65	3.476	7.541	4.167	3.960	3.728	.207	.232	1.630	1.443	5.171	4.0	4.5	8.5
1.70	3.582	7.554	4.150	3.949	3.725	.201	.224	1.679	1.437	5.162	3.9	4.4	8.3
1.75	3.687	7.567	4.100	3.905	3.690	.195	.215	1.728	1.432	5.122	3.8	4.2	8.0
1.80	3.793	7.579	4.030	3.841	3.635	.189	.206	1.778	1.428	5.063	3.8	4.1	7.9
1.85	3.898	7.591	3.952	3.768	3.564	.184	.204	1.827	1.423	4.987	3.7	4.1	7.8
1.90	4.003	7.602	3.869	3.688	3.483	.181	.205	1.876	1.418	4.901	3.7	4.2	7.9
1.95	4.109	7.614	3.783	3.609	3.398	.174	.211	1.925	1.414	4.812	3.6	4.4	8.0
2.00	4.214	7.625	3.698	3.527	3.312	.171	.215	1.975	1.410	4.722	3.6	4.6	8.2
2.05	4.319	7.635	3.612	3.442	3.229	.170	.213	2.025	1.406	4.635	3.7	4.6	8.3

*These columns should be multiplied by 10^{-3}

NOTES:

Column 7	=	Column 4 − Column 5
Column 8	=	Column 5 − Column 6
Column 12	=	Column 7 ÷ Column 11
Column 13	=	Column 8 ÷ Column 11
Column 14	=	Column 12 + Column 13

PLATE XX - MODEL 3878-1 DATA CALCULATION SHEET

MODEL 3878-1 SHIP DD 710

LBP 20.759 ft. ν = $1.2817\text{x}10^{-5}$ LBP 383.0 FT

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.2463\text{x}10^{7} \qquad \frac{1.6889(L)^{3/2}}{\nu} = 9.8768\text{x}10^{8}$$

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$V/\sqrt{L}$	$\times10^7$ N_R MODEL	Log_{10} N_R	C_{rAA}*	C_{rWR}*	C_{rBH}*	ΔC_r* RUD	ΔC_r* S&S	$\times10^9$ N_R SHIP	C_f* SHIP	C_{tBH}* SHIP	% RUD	% S&S	% TOT
0.55	.685	6.835	1.089	1.030	.713	.059	.317	0.543	1.653	2.742	2.5	13.6	16.1
0.60	.748	6.874	1.190	1.127	.809	.063	.318	0.593	1.634	2.824	2.6	13.2	15.8
0.65	.810	6.909	1.283	1.219	.925	.064	.294	0.642	1.618	2.901	2.5	11.7	14.2
0.70	.872	6.941	1.331	1.263	1.010	.068	.253	0.691	1.603	2.934	2.6	9.8	12.4
0.75	.935	6.971	1.354	1.300	1.047	.054	.253	0.741	1.589	2.943	2.1	9.7	11.8
0.80	.997	6.999	1.431	1.391	1.144	.040	.247	0.790	1.576	3.007	1.5	9.2	10.7
0.85	1.059	7.025	1.516	1.452	1.252	.064	.200	0.840	1.564	3.080	2.3	7.2	9.5
0.90	1.122	7.050	1.555	1.500	1.292	.055	.208	0.889	1.553	3.108	2.0	7.4	9.4
0.95	1.184	7.073	1.698	1.652	1.421	.046	.231	0.938	1.543	3.241	1.6	7.8	9.4
1.00	1.246	7.096	1.870	1.834	1.609	.038	.223	0.988	1.533	3.403	1.2	7.2	8.4
1.05	1.309	7.117	2.007	1.970	1.760	.037	.210	1.037	1.524	3.531	1.1	6.4	7.5
1.10	1.371	7.137	2.066	2.023	1.781	.043	.242	1.086	1.516	3.582	1.3	7.4	8.7
1.15	1.433	7.156	2.132	2.057	1.801	.073	.256	1.136	1.507	3.639	2.2	7.8	10.0
1.20	1.496	7.175	2.269	2.158	1.913	.111	.245	1.185	1.500	3.769	3.3	7.2	10.5
1.25	1.558	7.193	2.464	2.379	2.121	.085	.258	1.235	1.492	3.956	2.4	7.2	9.6
1.30	1.620	7.210	2.749	2.645	2.412	.104	.233	1.284	1.485	4.234	2.7	6.0	8.7
1.35	1.682	7.226	3.116	2.944	2.784	.168	.160	1.333	1.478	4.594	4.0	3.8	7.8
1.40	1.745	7.242	3.441	3.249	3.098	.192	.151	1.383	1.472	4.913	4.2	3.3	7.5
1.45	1.807	7.257	3.705	3.520	3.337	.185	.183	1.432	1.466	5.171	3.9	3.8	7.7
1.50	1.869	7.272	3.899	3.722	3.512	.177	.210	1.482	1.459	5.358	3.6	4.2	7.8
1.55	1.932	7.286	4.037	3.866	3.636	.171	.230	1.531	1.454	5.491	3.4	4.5	7.9
1.60	1.994	7.300	4.130	3.948	3.713	.182	.235	1.580	1.448	5.578	3.5	4.6	8.1
1.65	2.056	7.313	4.160	3.978	3.751	.202	.227	1.630	1.443	5.603	3.9	4.4	8.3
1.70	2.119	7.326	4.141	3.969	3.748	.172	.221	1.679	1.437	5.573	3.3	4.3	7.6
1.?5	2.181	7.339	4.096	3.936	3.709	.160	.227	1.728	1.432	5.528	3.1	4.4	7.5
1.80	2.243	7.351	4.037	3.882	3.646	.155	.236	1.778	1.428	5.465	3.1	4.7	7.8
1.85	2.306	7.363	3.969	3.815	3.576	.154	.239	1.82?	1.423	5.392	3.1	4.8	7.9
1.90	2.368	7.374	3.897	3.739	3.502	.158	.23?	1.876	1.418	5.315	3.2	4.8	8.0
1.95	2.430	7.386	3.816	3.658	3.421	.158	.237	1.925	1.414	5.230	3.3	4.9	8.2
2.00	2.493	7.397	3.732	3.569	3.336	.163	.233	1.975	1.410	5.142	3.4	4.9	8.3
2.05	2.555	7.408	3.647	3.478	3.249	.169	.229	2.025	1.406	5.053	3.6	4.9	8.5

*These columns should be multiplied by 10^{-3}

NOTES:

Column 7	=	Column 4	−	Column 5
Column 8	=	Column 5	−	Column 6
Column 12	=	Column 7	÷	Column 11
Column 13	=	Column 8	÷	Column 11
Column 14	=	Column 12	+	Column 13

PLATE XXI - MODEL 4007 DATA CALCULATION SHEET

MODEL 4007 SHIP DD 710

LBP 12.00 ft. $\nu = 1.2817 \times 10^{-5}$ LBP 383.0 FT

$$\frac{1.6889(L)^{3/2}}{\nu} = 0.54776 \times 10^{7} \qquad \frac{1.6889(L)^{3/2}}{\nu} = 9.8768 \times 10^{8}$$

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$V/\sqrt{L}$	$\times 10^7$ N_R MODEL	Log_{10} N_R	C_{rAA}*	C_{rWR}*	C_{rBH}*	ΔC_r* RUD	ΔC_r* S&S	$\times 10^9$ N_R SHIP	C_f* SHIP	C_{tBH}* SHIP	% RUD	% S&S	% TOT
0.55	.301	6.479	1.230	1.212	.768	.018	.444	0.543	1.653	2.421	.7	18.3	19.0
0.60	.329	6.517	1.260	1.240	.818	.020	.422	0.593	1.634	2.452	.8	17.2	18.0
0.65	.356	6.551	1.285	1.265	.868	.020	.397	0.642	1.618	2.486	.8	16.0	16.8
0.70	.383	6.583	1.301	1.272	.920	.029	.403	0.691	1.603	2.523	1.1	16.0	17.1
0.75	.411	6.614	1.370	1.322	.996	.048	.352	0.741	1.589	2.585	1.9	13.6	15.5
0.80	.438	6.642	1.487	1.422	1.120	.065	.302	0.790	1.576	2.696	2.4	11.2	13.6
0.85	.466	6.668	1.500	1.432	1.148	.068	.284	0.840	1.564	2.712	2.5	10.5	13.0
0.90	.493	6.693	1.534	1.468	1.192	.066	.276	0.889	1.553	2.745	2.4	10.0	12.4
0.95	.520	6.716	1.659	1.585	1.315	.074	.270	0.938	1.543	2.858	2.6	9.4	12.0
1.00	.548	6.739	1.843	1.791	1.504	.052	.287	0.988	1.533	3.037	1.7	9.5	11.2
1.05	.575	6.760	1.948	1.904	1.624	.044	.280	1.037	1.524	3.148	1.4	9.0	10.4
1.10	.602	6.780	2.006	1.952	1.664	.054	.288	1.086	1.516	3.180	1.7	9.1	10.8
1.15	.630	6.799	2.081	1.989	1.708	.092	.279	1.136	1.507	3.215	2.9	8.7	11.6
1.20	.657	6.818	2.218	2.095	1.836	.123	.263	1.185	1.500	3.336	3.7	8.0	11.7
1.25	.685	6.836	2.439	2.345	2.080	.094	.265	1.284	1.485	3.872	3.7	7.4	11.1
1.30	.712	6.853	2.815	2.672	2.387	.143	.285	1.284	1.485	3.872	3.7	7.4	11.1
1.35	.739	6.869	3.190	3.030	2.737	.160	.293	1.333	1.478	4.215	3.8	7.0	10.8
1.40	.767	6.885	3.503	3.358	3.130	.145	.228	1.383	1.472	4.602	3.2	5.0	8.2
1.45	.794	6.900	3.764	3.620	3.416	.144	.204	1.432	1.466	4.882	3.0	4.2	7.2
1.50	.822	6.915	3.981	3.812	3.594	.169	.218	1.482	1.459	5.053	3.4	4.3	7.7
1.55	.849	6.929	4.135	3.954	3.710	.181	.244	1.531	1.454	5.164	3.5	4.8	8.3
1.60	.876	6.943	4.218	4.043	3.777	.175	.266	1.580	1.448	5.225	3.4	5.1	8.5
1.65	.904	6.956	4.249	4.076	3.804	.173	.272	1.630	1.443	5.247	3.3	5.2	8.5
1.70	.931	6.969	4.239	4.072	3.796	.167	.276	1.679	1.437	5.233	3.2	5.3	8.5
1.75	.958	6.981	4.210	4.035	3.755	.175	.280	1.728	1.432	5.187	3.4	5.4	8.8
1.80	.986	6.994	4.145	3.971	3.696	.174	.275	1.778	1.428	5.124	3.4	5.4	8.8
1.85	1.013	7.006	4.075	3.899	3.630	.176	.269	1.327	1.423	5.053	3.5	5.3	8.8
1.90	1.041	7.018	3.998	3.821	3.556	.177	.265	1.876	1.418	4.974	3.6	5.4	9.0
1.95	1.068	7.029	3.915	3.740	3.478	.175	.262	1.925	1.414	4.892	3.6	5.4	9.0
2.00	1.096	7.040	3.832	3.658	3.396	.174	.262	1.975	1.410	4.806	3.6	5.5	9.1
2.05	1.123	7.050	3.743	3.572	3.313	.171	.259	2.025	1.406	4.719	3.6	5.5	9.1

*These columns should be multiplied by 10^{-3}

NOTES:

Column 7	=	Column 4	−	Column 5
Column 8	=	Column 5	−	Column 6
Column 12	=	Column 7	÷	Column 11
Column 13	=	Column 8	÷	Column 11
Column 14	=	Column 12	+	Column 13

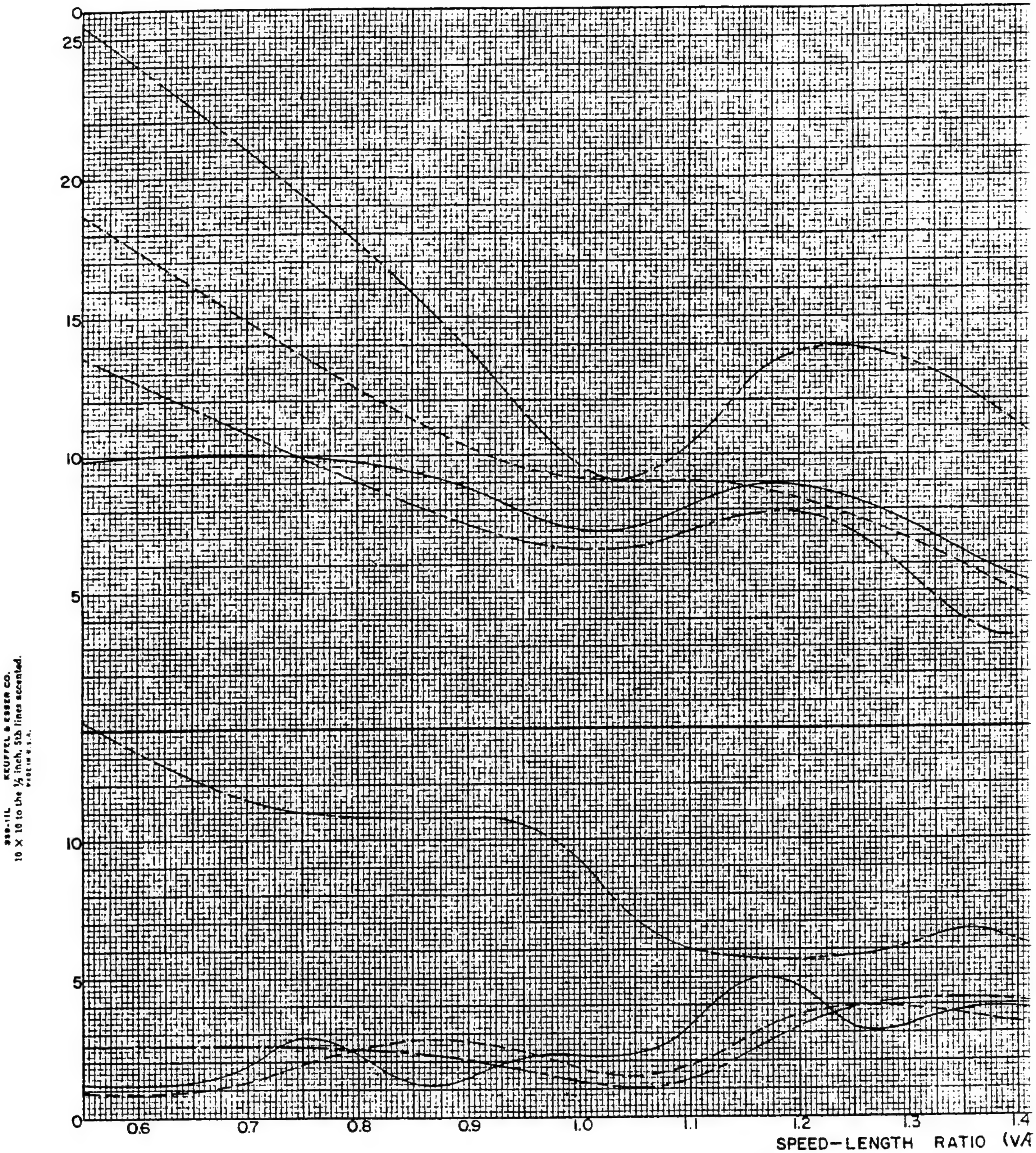
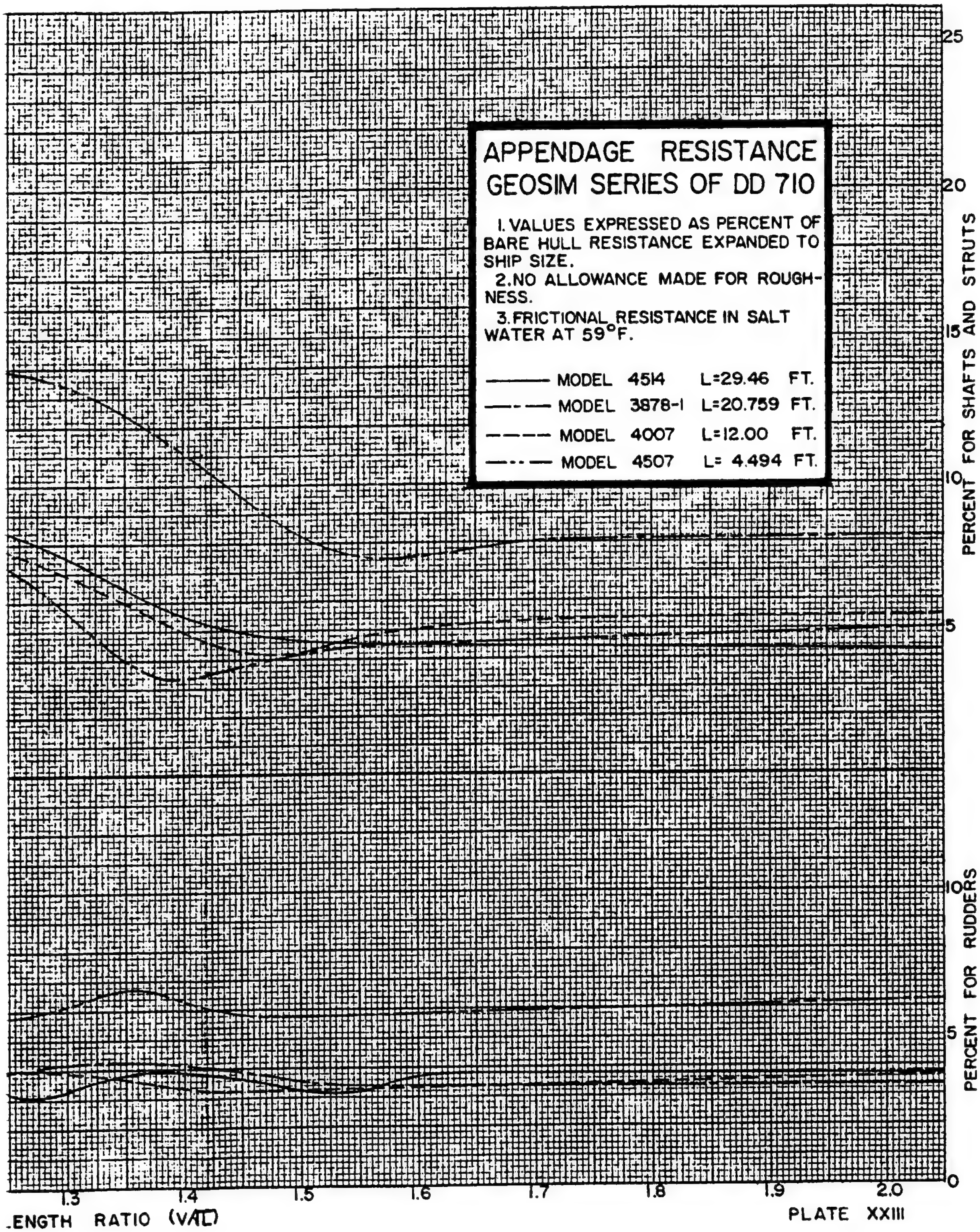


PLATE XXIII - Curves of Percent Increase in Drag for Rudders and. Shafts and Struts for Geosim Series of DD710



n Series of DD710

PLATE XXII - MODEL 4507 DATA CALCULATION SHEET

MODEL <u>4507</u> SHIP <u>DD 710</u>

LBP <u>4.494 ft.</u> ν = <u>1.2817x10 $^{-5}$</u> LBP <u>383.0 FT</u>

$$\frac{1.6889(L)^{3/2}}{\nu} = 1.2554\text{x}10^{6} \qquad \frac{1.6889(L)^{3/2}}{\nu} = 9.8768\text{x}10^{8}$$

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$V/\sqrt{L}$	$\times 10^6$ N_R MODEL	$Log10$ N_R	C_{rAA}*	C_{rWR}*	C_{rBH}*	ΔC_r* RUD	ΔC_r* S&S	$\times 10^9$ N_R SHIP	C_f* SHIP	C_{tBH}* SHIP	% RUD	% S&S	% TOT
0.55	.690	5.839	1.763	1.419	.801	.344	.618	0.543	1.653	2.454	14.0	25.2	39.2
0.60	.753	5.877	1.729	1.408	.835	.321	.573	0.593	1.634	2.469	13.1	23.5	36.6
0.65	.816	5.912	1.704	1.401	.859	.303	.542	0.642	1.618	2.477	12.4	22.1	34.5
0.70	.879	5.944	1.696	1.399	.869	.297	.530	0.691	1.603	2.472	12.1	21.7	33.8
0.75	.942	5.974	1.619	1.368	.870	.251	.498	0.741	1.589	2.459	10.3	20.5	30.8
0.80	1.004	6.002	1.648	1.345	.966	.303	.376	0.790	1.576	2.542	12.0	14.9	26.9
0.85	1.067	6.028	1.730	1.452	1.083	.278	.369	0.840	1.564	2.647	10.8	14.3	25.1
0.90	1.130	6.053	1.760	1.525	1.130	.235	.395	0.889	1.553	2.683	8.8	14.9	23.7
0.95	1.193	6.077	1.920	1.573	1.215	.347	.358	0.938	1.543	2.758	12.7	13.1	25.8
1.00	1.255	6.099	2.087	1.790	1.508	.297	.282	0.988	1.533	3.041	9.8	9.3	19.1
1.05	1.318	6.120	2.181	1.960	1.666	.221	.294	1.037	1.524	3.190	7.0	9.3	16.3
1.10	1.381	6.140	2.228	2.037	1.712	.191	.325	1.086	1.516	3.228	6.0	10.1	16.1
1.15	1.444	6.160	2.318	2.132	1.731	.186	.401	1.136	1.507	3.238	5.8	12.5	18.3
1.20	1.506	6.178	2.490	2.297	1.817	.193	.480	1.185	1.500	3.317	5.9	14.6	20.5
1.25	1.569	6.196	2.743	2.540	2.042	.203	.498	1.235	1.492	3.534	5.8	14.2	20.0
1.30	1.632	6.213	3.090	2.860	2.390	.230	.470	1.284	1.485	3.875	6.0	13.1	19.1
1.35	1.695	6.229	3.535	2.248	2.799	.287	.449	1.333	1.478	4.277	6.7	10.6	17.3
1.40	1.758	6.245	3.961	3.670	3.175	.291	.495	1.383	1.472	4.647	6.3	10.7	17.0
1.45	1.820	6.260	4.260	3.980	3.496	.280	.484	1.432	1.466	4.962	5.7	9.8	15.5
1.50	1.883	6.275	4.468	4.175	3.736	.293	.439	1.482	1.459	5.195	5.7	8.5	14.2
1.55	1.946	6.289	4.604	4.297	3.898	.307	.399	1.531	1.454	5.352	5.8	7.5	13.3
1.60	2.009	6.303	4.680	4.370	3.967	.310	.403	1.580	1.448	5.415	5.7	7.5	13.2
1.65	2.071	6.316	4.707	4.403	3.983	.304	.420	1.630	1.443	5.426	5.6	7.8	13.4
1.70	2.134	6.329	4.701	4.399	3.963	.302	.436	1.679	1.437	5.400	5.6	8.1	13.7
1.75	2.197	6.342	4.668	4.356	3.920	.312	.436	1.728	1.432	5.352	5.8	8.2	14.0
1.80	2.260	6.354	4.609	4.287	3.858	.322	.429	1.778	1.428	5.286	6.1	8.2	14.3
1.85	2.322	6.366	4.529	4.207	3.787	.322	.420	1.827	1.423	5.210	6.2	8.1	14.3
1.90	2.385	6.378	4.438	4.118	3.712	.320	.406	1.876	1.418	5.130	6.3	8.0	14.3
1.95	2.448	6.389	4.340	4.028	3.628	.312	.400	1.925	1.414	5.042	6.2	8.0	14.2
2.00	2.511	6.399	4.240	3.935	3.541	.305	.394	1.975	1.410	4.951	6.2	8.0	14.2
2.05	2.574	6.411	4.137	3.840	3.453	.297	.387	2.025	1.406	4.859	6.1	8.0	14.1

*These columns should be multiplied by 10^{-3}

NOTES:

Column 7	=	Column 4	–	Column 5
Column 8	=	Column 5	–	Column 6
Column 12	=	Column 7	÷	Column 11
Column 13	=	Column 8	÷	Column 11
Column 14	=	Column 12	+	Column 13

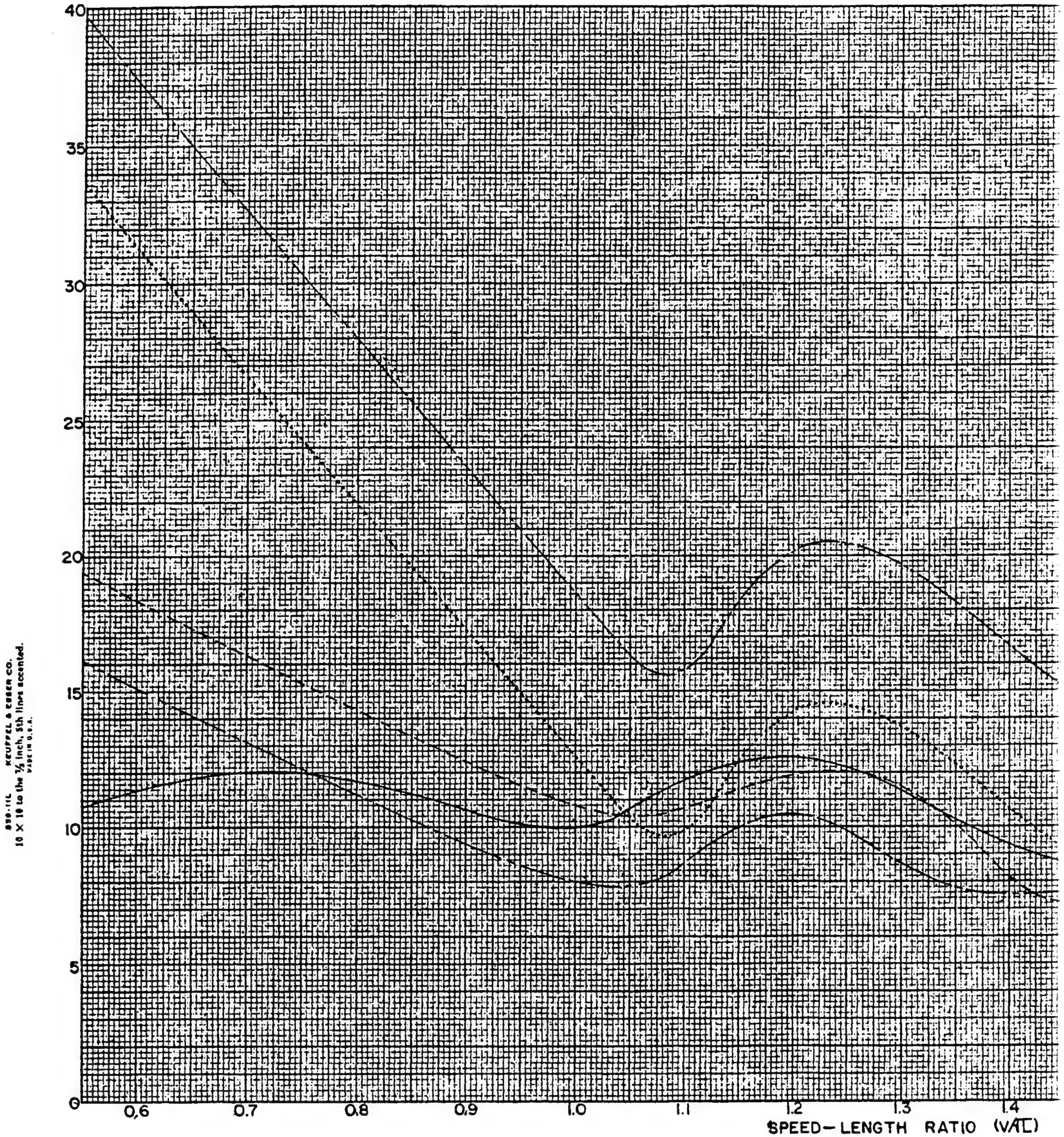
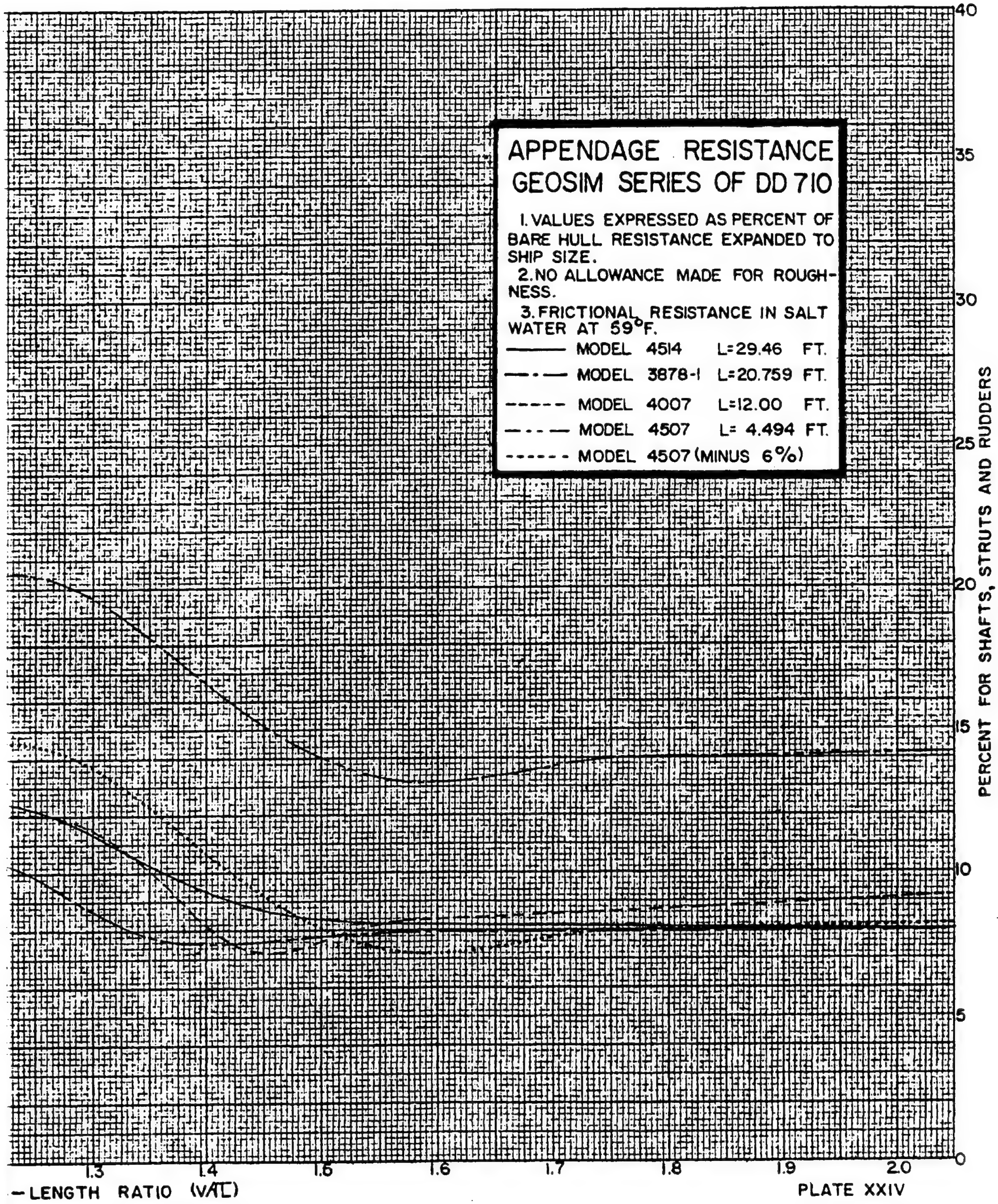


PLATE XXIV - Curves of Percent Increase in Drag for Shafts, Struts, and Rudder for Geosim Series of DD710



;eries of DD710

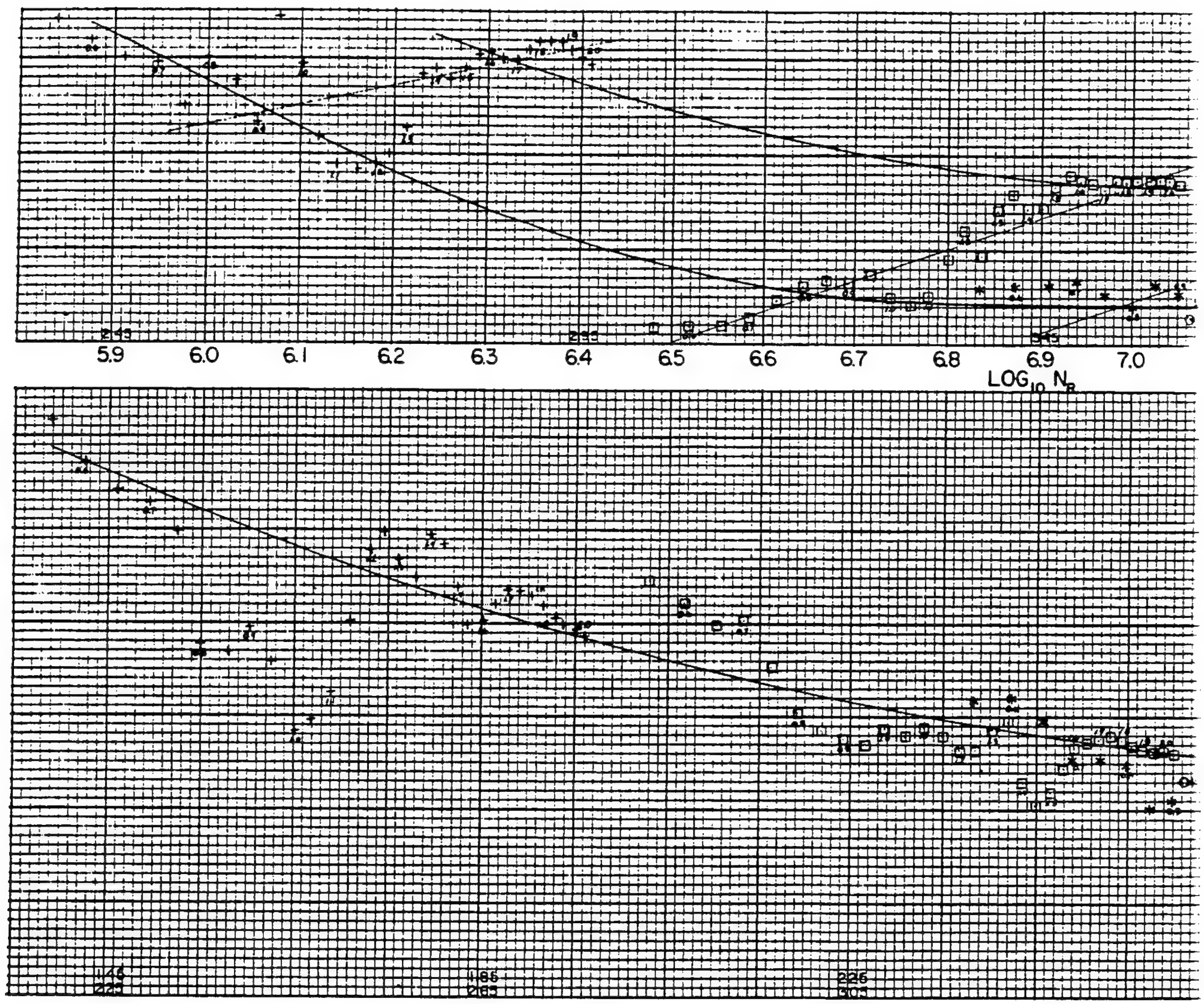


PLATE XXV - Curves of Increase in C_t for Rudders and, Shafts and Struts for Geosim Series of DD710

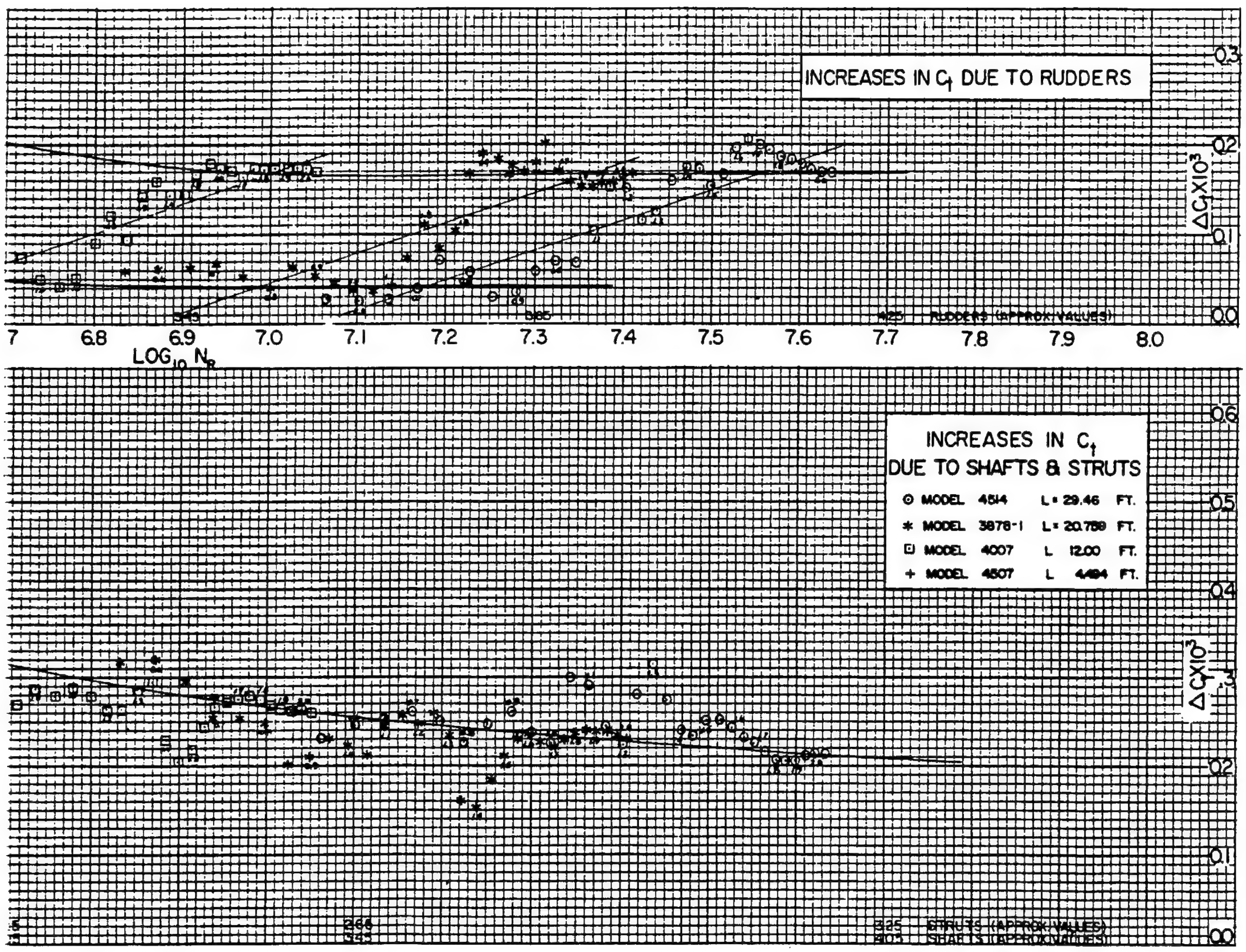


PLATE XXV

osim Series of DD710

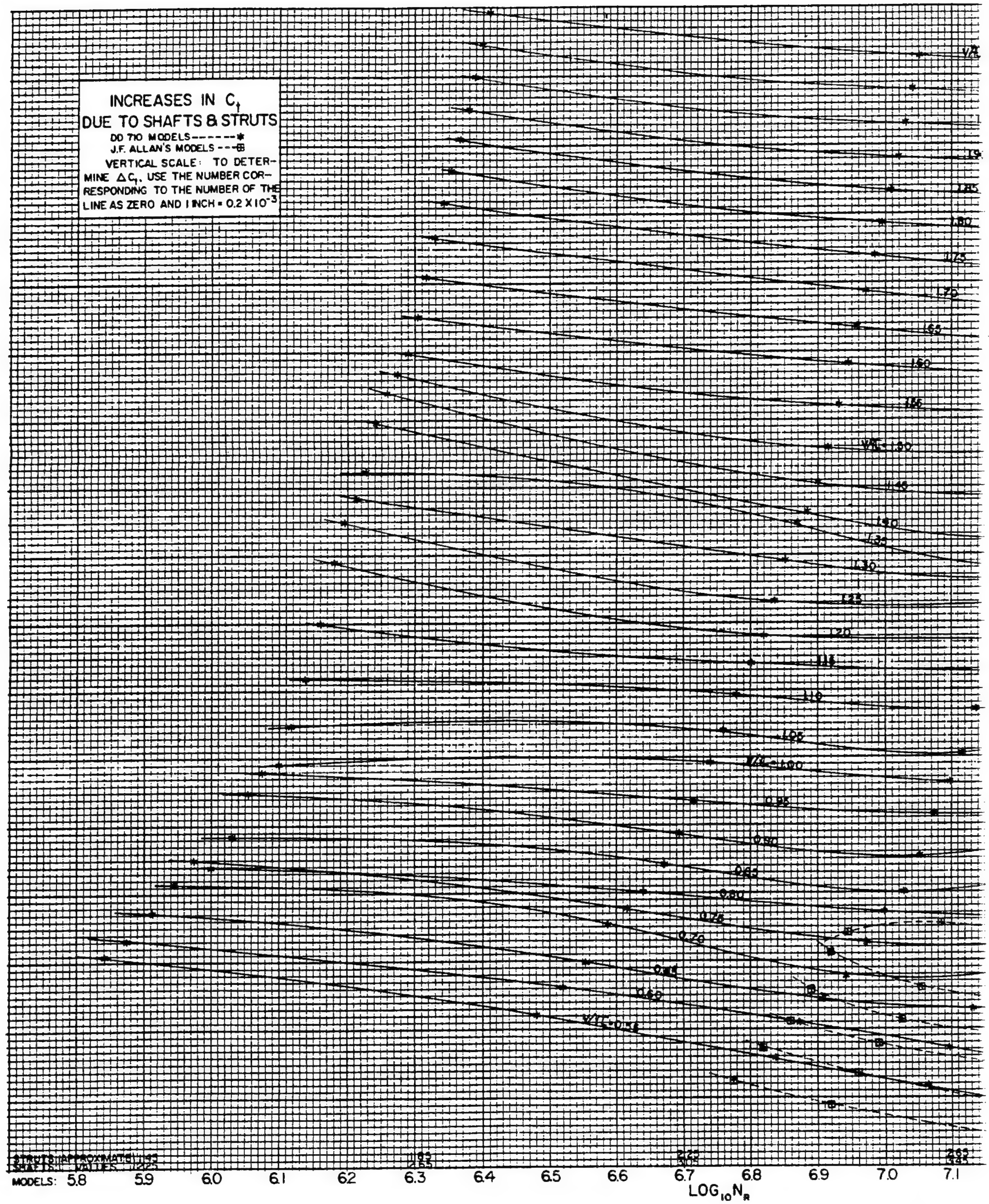
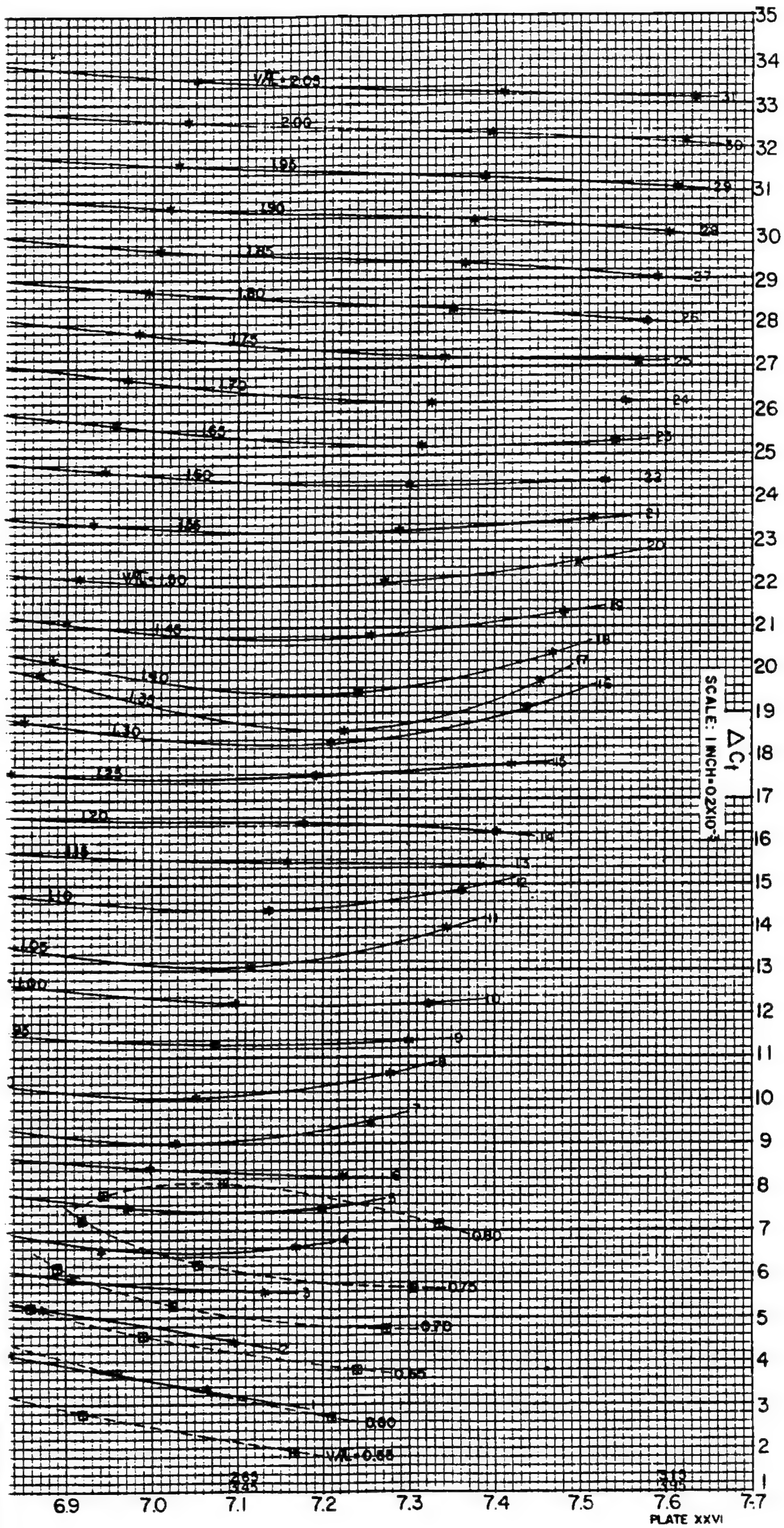


PLATE XXVI - Curves of Increase in C_t for Shafts and Struts at specific Speed-Length Ratios for Geosim Series of



ɔs for Geosim Series of DD710

PLATE XXVII - BOUNDARY LAYER THICKNESS CALCULATION

$$\delta = 5.5\left(\frac{\nu X}{V}\right)^{1/2} = 5.5\left[\frac{\nu(X/L)}{V/\sqrt{L}}\right]^{1/2}(L)^{1/4} = \frac{0.191}{\left(V/\sqrt{L}\right)^{1/2}}(L)^{1/4},\text{ where}$$

$X = 0.785\ L$ and $\nu = 1.2817 \times 10^{-5}$

L	29.46	ft.	$(L)^{1/4}$	2.33
L	20.759	ft.	$(L)^{1/4}$	2.134
L	12.00	ft.	$(L)^{1/4}$	1.861
L	4.494	ft.	$(L)^{1/4}$	1.456

		Model 1514			Model 3878-1			Model 4007			Model 4507		
$\frac{V}{\sqrt{L}}$	$\frac{0.191}{(V\sqrt{L})^{1/2}}$	δ	% RUD	% S&S	δ	% RUD	% S&S	δ	% RUD	% S&S	δ	% RUD	% S&S
0.55	0.258	0.60	1.2	9.8	0.551	2.5	13.6	0.481	0.7	18.3	0.376	14.0	25.2
0.60	0.248	0.57	1.1	10.0	0.528	2.6	13.2	0.461	0.8	17.2	0.361	13.1	25.5
0.65	0.237	0.55	1.2	10.1	0.507	2.5	11.7	0.442	0.8	16.0	0.345	12.4	22.1
0.70	0.228	0.53	1.6	10.3	0.488	2.6	9.8	0.426	1.1	16.0	0.333	12.1	21.7
0.75	0.221	0.51	2.9	9.7	0.472	2.1	9.7	0.411	1.9	13.6	0.322	10.3	20.5
0.80	0.214	0.49	2.2	8.4	0.458	1.5	9.2	0.399	2.4	11.2	0.313	12.0	14.9
0.85	0.207	0.48	1.2	9.0	0.443	2.3	7.2	0.387	2.5	10.5	0.303	10.8	14.3
0.90	0.202	0.47	1.3	9.3	0.432	2.0	7.4	0.376	2.4	10.0	0.293	8.8	14.9
0.95	0.197	0.45	2.1	8.0	0.420	1.6	7.8	0.366	2.6	9.4	0.287	12.7	13.1
1.00	0.191	0.44	2.3	7.2	0.408	1.2	7.2	0.256	1.7	9.5	0.278	9.8	9.3
1.05	0.187	0.43	2.2	9.5	0.398	1.1	6.4	0.348	1.4	9.0	0.273	7.0	9.3
1.10	0.182	0.42	3.2	9.1	0.389	1.3	6.4	0.340	1.4	9.0	0.226	7.0	9.3
1.15	0.179	0.41	4.9	7.6	0.381	2.2	7.8	0.333	2.9	8.7	0.260	5.8	12.5
1.20	0.175	0.40	4.6	6.8	0.373	3.3	7.2	0.326	3.7	8.0	0.254	5.9	14.6
1.25	0.171	0.40	3.3	8.0	0.366	2.4	7.2	0.319	2.6	7.5	0.250	5.8	14.2
1.30	0.168	0.39	3.3	8.3	0.359	2.7	6.0	0.313	3.7	7.4	0.245	6.0	13.1
1.35	0.165	0.38	3.9	6.6	0.352	4.0	3.8	0.307	3.8	7.0	0.240	6.7	10.6
1.40	0.162	0.37	3.9	5.4	0.345	4.2	3.3	0.301	3.2	5.0	0.234	6.3	10.7
1.45	0.159	0.36	3.7	5.0	0.338	3.9	3.8	0.295	3.0	4.2	0.231	5.7	9.8
1.50	0.156	0.36	3.2	5.2	0.333	3.6	4.2	0.290	3.4	4.3	0.228	5.7	8.5
1.55	0.154	0.35	3.3	5.0	0.328	3.4	4.5	0.286	3.5	4.8	0.224	5.8	7.5
1.60	0.152	0.35	3.8	4.7	0.323	3.5	4.6	0.283	3.4	5.1	0.221	5.7	7.5
1.65	0.150	0.34	4.0	4.5	0.319	3.9	4.4	0.278	3.3	5.2	0.218	5.6	7.8
1.70	0.147	0.34	3.9	4.4	0.315	3.3	4.3	0.274	3.2	5.3	0.215	5.6	8.1
1.75	0.145	0.33	3.8	4.2	0.310	3.1	4.4	0.271	3.4	5.4	0.211	5.8	8.2
1.80	0.143	0.33	3.8	4.1	0.305	3.1	4.7	0.266	3.4	5.4	0.208	6.1	8.2
1.85	0.141	0.32	3.7	4.1	0.300	3.1	4.8	0.262	3.5	5.3	0.205	6.2	8.1
1.90	0.139	0.32	3.7	4.2	0.296	3.2	4.8	0.257	3.6	5.4	0.201	6.3	8.0
1.95	0.136	0.31	3.6	4.4	0.291	3.3	4.9	0.254	3.6	5.4	0.198	6.2	8.0
2.00	0.135	0.31	3.6	4.6	0.288	3.4	4.9	0.252	3.6	5.5	0.197	6.2	8.0
2.05	0.134	0.31	3.7	4.6	0.286	3.6	4.9	0.250	3.6	5.5	0.195	6.1	8.0

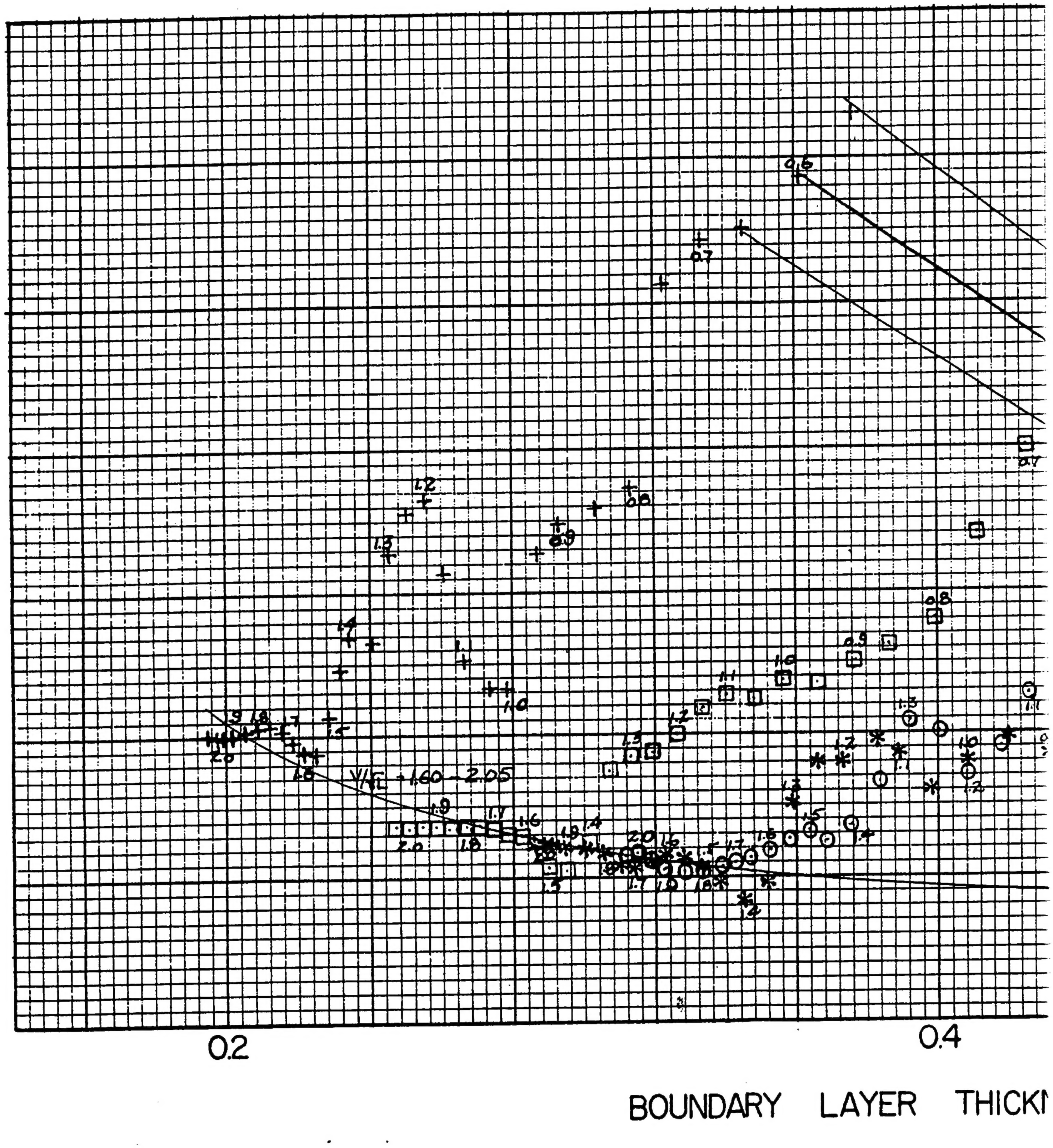


PLATE XXVIII - Curves of Percent Increase in Drag for Shafts and Struts as a Function of Boundary Layer Thickne

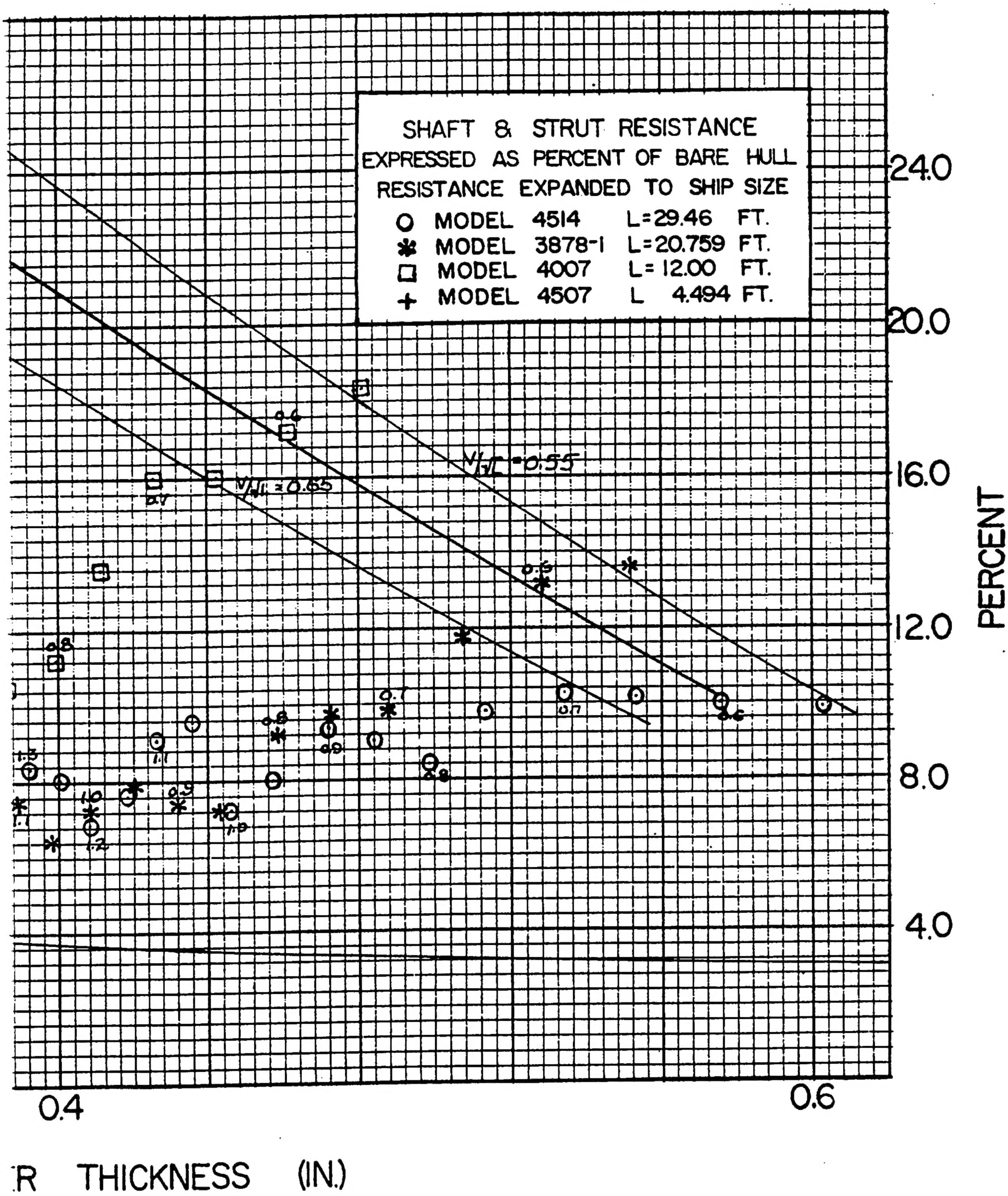


PLATE XXVIII

-y Layer Thickness for Geosim Series of DD710

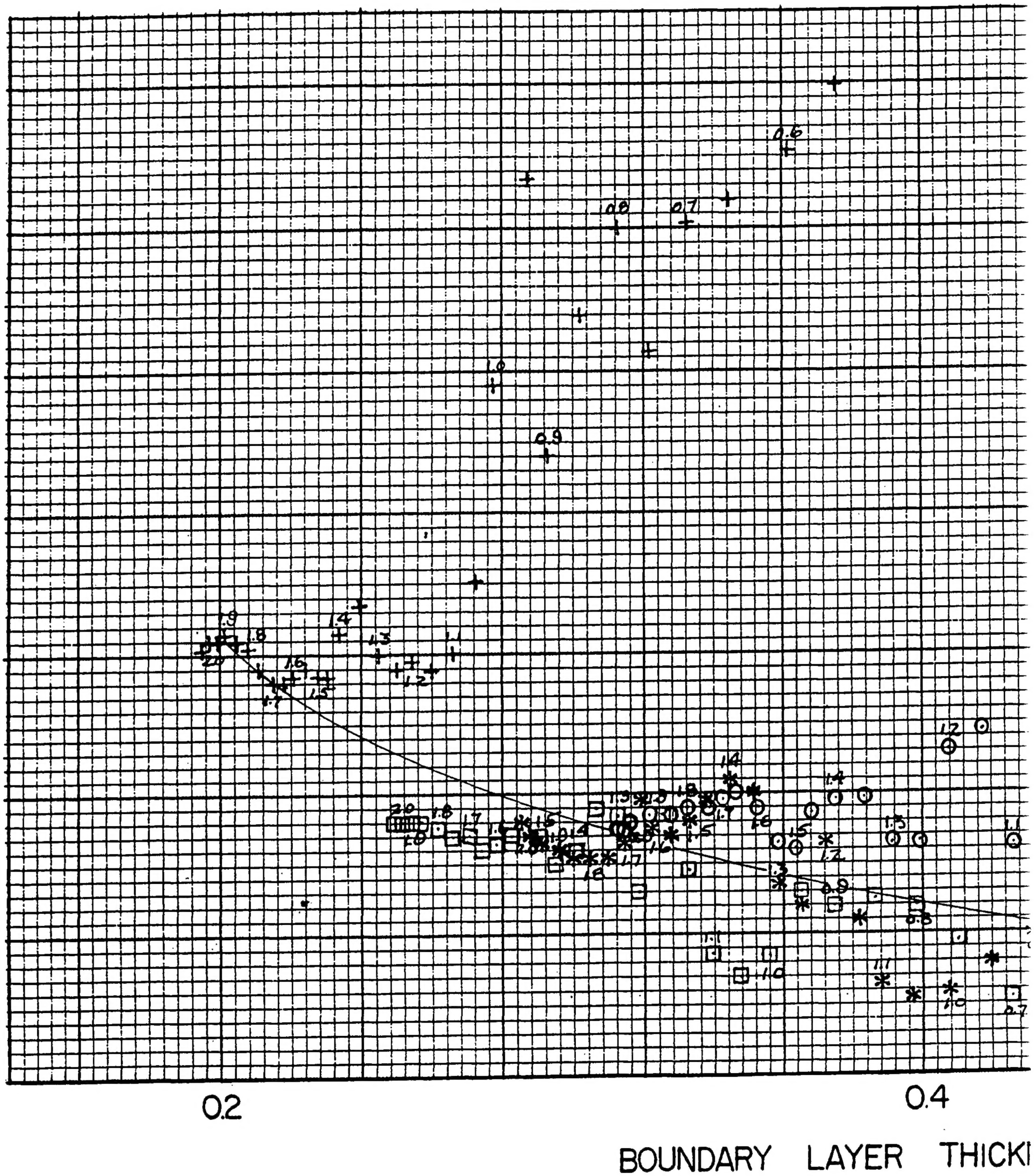


PLATE XXIX - Curves of Percent Increase in Drag for Rudder as a Function of Boundary Layer Thickness fo

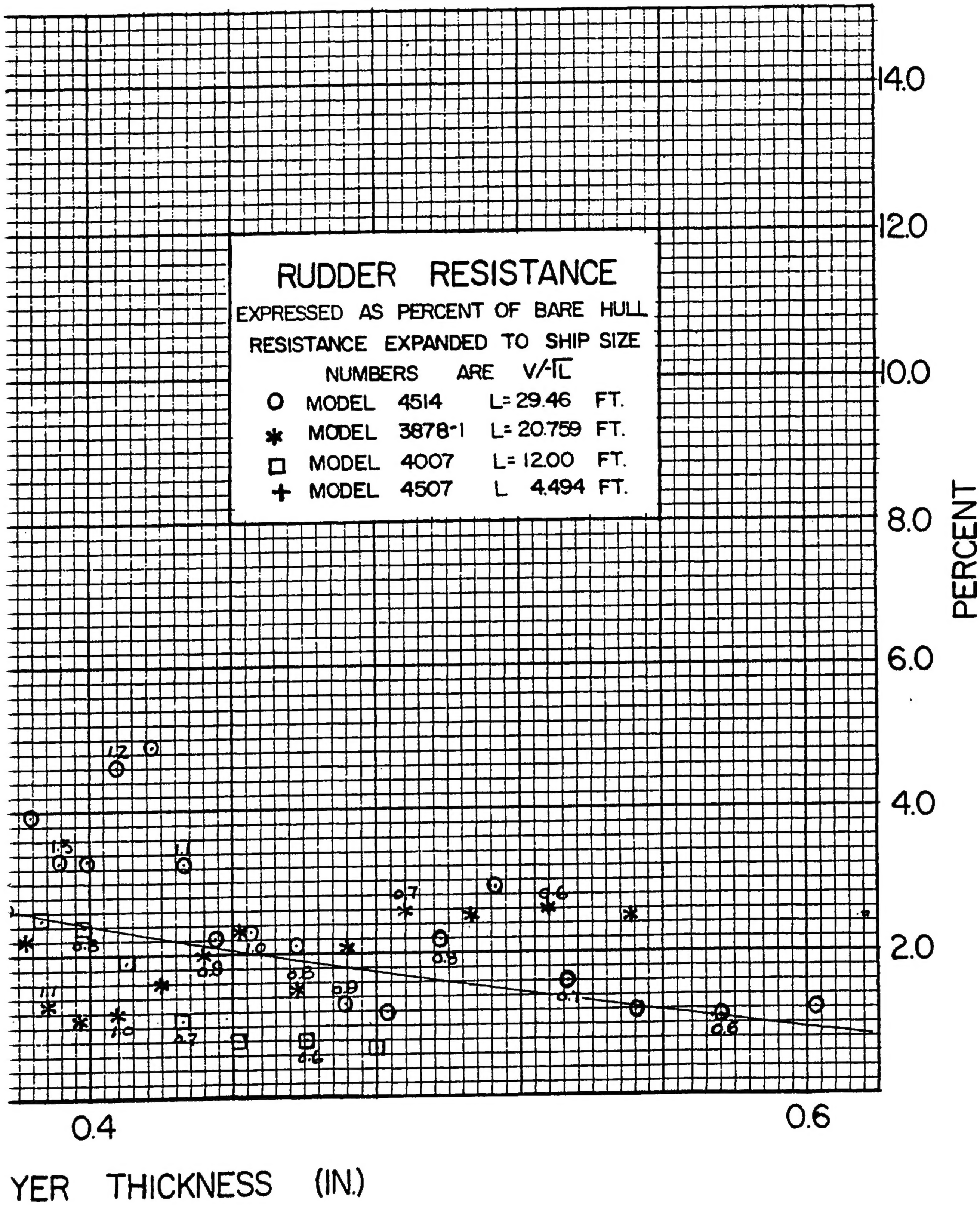


PLATE XXIX

Layer Thickness for Geosim Series of DD710